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ABSTRACT

We have studied over 1600 Am stars at a photometric precision of 1 mmag with SuperWASP photometric data. Contrary to previous belief, we find that around 200 Am stars are pulsating δ Sct and γ Dor stars, with low amplitudes that have been missed in previous, less extensive studies. While the amplitudes are generally low, the presence of pulsation in Am stars places a strong constraint on atmospheric convection, and may require the pulsation to be laminar. While some pulsating Am stars have been previously found to be δ Sct stars, the vast majority of Am stars known to pulsate are presented in this paper. They will form the basis of future statistical studies of pulsation in the presence of atomic diffusion.

Key words. Asteroseismology – Stars: chemically peculiar – Stars: oscillations – Stars: variables: delta Scuti – Techniques: photometry

1. Introduction

In the region of the Hertzsprung-Russell (HR) diagram where the Cepheid instability strip extends across the main sequence, there is a complex relationship between stellar pulsation and atmospheric abundance anomalies that is not fully understood. This region ranges from the early A stars to mid-F stars in spectral type, and from the zero age main sequence to the terminal age main sequence in luminosity. Found here are the strongly magnetic chemically peculiar Ap and Fp stars, the non-magnetic metallic-lined Am stars, the rarer metal-deficient λ Boo stars, the pulsating δ Sct stars, γ Dor stars and rapidly oscillating Ap (roAp) stars. Much has been written about these stars and their physics, which we briefly summarise here. For more detailed discussions see Joshi et al. (2006), Kurtz & Martinez (2000) and Kurtz (1989, 1978, 1976).

Most stars in the main-sequence region of the instability strip are normal abundance δ Sct stars with relatively high rotational velocities – usually $v \sin i \geq 100\,\mathrm{km\,s^{-1}}$. A large fraction of A stars are Am stars, peaking at around 50 per cent at A8, but Am stars are believed either not to pulsate as δ Sct stars, or may do so with much smaller amplitudes than the normal abundance δ Sct stars. Am stars are mostly found in short period binary systems with orbital periods between 1 – 10 d, causing synchronous rotation with $v \sin i \leq 120\,\mathrm{km\,s^{-1}}$ (Abt, 2009); a few single Am stars with similar slow rotation are known.

The magnetic Ap stars are rarer, constituting less than 10 per cent of the A stars. They have very strong global magnetic fields and are often roAp stars with high overtone p mode pulsations with much shorter periods than the δ Sct stars. No Ap star is known to be a δ Sct star. Our physical understanding is that atomic diffusion – radiative levitation and gravitational settling – stabilises the slowly rotating Am and Ap stars so that low overtone p modes are not excited; particularly important in this context is the gravitational settling of helium from the He II ionisation zone where the κ-mechanism drives the pulsation of δ Sct stars (see Aerts et al. 2010). Otherwise, the more rapidly rotating stars remain mixed because of turbulence induced by meridional circulation and are excited by the κ-mechanism (Turcotte et al., 2000).

The understanding of the relationship of the long-established δ Sct stars to the more recently discovered γ Dor stars is currently in flux. Previously, the δ Sct stars were known as p mode pulsators, while the γ Dor stars were known as g mode pulsators. The instability strips for these classes of stars partially overlap, and some "hybrid" stars were discovered with pulsation in both

⋆ An extended version of Table 1 containing all the detected frequencies and amplitudes is only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/

p modes and g modes. A striking case is that of HD 8801, which is an Am star that shows both δ Sct and γ Dor p-mode and g-mode pulsation (Henry & Fekel, 2005).

Hybrid stars that show both p modes and g modes are of particular interest asteroseismically because the p modes characterise the conditions primarily in the outer part of the star, while the g modes test the core conditions. Now with data from the *Kepler* Mission, which is obtaining nearly continuous data for over 150 000 stars for 3.5 y, mostly with 30-min cadence, but for 512 stars with 1-min cadence (Gilliland et al., 2010), the Kepler Asteroseismic Science Consortium (KASC) is studying numbers of δ Sct stars and γ Dor stars at μmag precision. It is becoming clear that hybrid stars are common and may be the norm, so that the classes of δ Sct and γ Dor stars are merging (Grigahcène et al., 2010). Interestingly, the latter authors find a possible correlation among the hybrid stars and Am spectral classification.

The *Kepler* Mission through KASC will model individual Am stars that are δ Sct pulsators with data of such high precision that new insight into the physics of the relationship between atomic diffusion and p mode pulsation will be obtained. But *Kepler* has a limited number of Am stars in its 105 deg^2 field-of-view. Another complementary source of information is to look at the statistics of pulsation in Am stars over the entire sky. That is now possible with the highly successful SuperWASP planetary transit-finding programme (Pollacco et al., 2006) that has surveyed a large fraction of both the northern and southern skies. There now exists in the SuperWASP archive over 290 billion photometric measurements for more than 30 million stars. These light curves encompass many types of stars, including the A stars in general, and Am stars in particular.

In this paper we have selected Am stars from the Renson & Manfroid (2009) catalogue of peculiar stars for which we have at least 1000 data points in SuperWASP light curves. While we do not detect pulsation in all of our programme stars, for around 200 metallic-lined stars out of over 1600 tested we find δ Sct pulsation. This is contrary to previous understanding that Am stars are constant in brightness. The reason we have gained this new understanding is that there has been no previous survey of so many Am stars, and previous studies have not all reached the SuperWASP detection threshold of only 1 mmag.

Many Am stars therefore *do* pulsate, generally with lower amplitude than normal abundance δ Sct stars. This amplitude difference is still to be understood in terms of atomic diffusion reducing pulsation driving for the slowly rotating Am stars, but there is not a complete lack of pulsation. That, has implications for turbulence in the diffusive layers and may require that the pulsation be laminar. Some striking examples of metallic-lined stars with relatively high pulsation amplitude (these are rare) address this question further, such as HD 188136 (Kurtz 1980; Wegner 1981) and HD 40765 (Kurtz et al., 1995). More constraints on the physics of the interaction of pulsation and atomic diffusion may also be found in stars that show *no* δ Sct p modes or γ Dor g modes at precisions of μmag. Some such A stars are known in the CoRoT and *Kepler* data sets, but in-depth studies have not yet been made, hence discussions of these have yet to be published.

The combination of the all-sky mmag precision of SuperWASP with the μmag precision of CoRoT and *Kepler* on selected stars, calls for new attempts to model the physics of the interaction of pulsation, rotation and atomic diffusion in the A stars.

2. Observations

The WASP project is surveying the sky for transiting extrasolar planets (Pollacco et al., 2006) using two robotic telescopes, one at the Observatorio del Roque de los Muchachos on the island of La Palma in the Canary Islands, and the other at the Sutherland Station, South African Astronomical Observatory (SAAO). Both telescopes consist of an array of eight 200-mm, f/1.8 Canon telephoto lenses and Andor CCDs, giving a field of view of $7.8^\circ \times 7.8^\circ$ and pixel size of around $14''$. The observing strategy is such that each field is observed with a typical cadence of the order of 10 min. WASP provides good quality photometry with a precision exceeding 1 per cent per observation in the approximate magnitude range $9 \leq V \leq 12$.

The SuperWASP data reduction pipeline is described in detail in Pollacco et al. (2006). The aperture-extracted photometry from each camera on each night are corrected for primary and secondary extinction, instrumental colour response and system zero-point relative to a network of local secondary standards. The resultant pseudo-V magnitudes are comparable to Tycho V magnitudes. Additional systematic errors affecting all the stars are identified and removed using the SysRem algorithm of Tamuz et al. (2005). The final light curves are stored in the WASP project's searchable archive (Butters et al., 2010).

3. Am star selection and analysis

We have selected Am stars from the Renson & Manfroid (2009) catalogue of peculiar stars for which we have data in the WASP archive and when individual light curves have at least 1000 data points (i.e. for a single camera and during a single season). Any stars known, or found, to be eclipsing binary systems were excluded from the analysis. Stars were also rejected when two approximately equal brightness stars were within the 3.5-pixel ($\sim 50''$) SuperWASP photometry aperture. However, unresolved close pairs in DSS images (separation $\lesssim 2''$) and systems with fainter companions ($\gtrsim 2$ mag) were retained.

For each individual light curve, periodograms were calculated using the fast computation of the Lomb periodogram method of Press & Rybicki (1989) as implemented in the Numerical Recipes FASPER routine (Press et al., 1992). Spectral window functions were also calculated, in order to identify peaks which had arisen due to the gaps in the observations. The periodograms were examined for any evidence of variability. Stars were rejected if the false alarm probability of the strongest peaks exceeded 0.1 (Horne & Baliunas, 1986). The remaining stars were examined in more detail using the PERIOD04 program (Lenz & Breger, 2005). For stars in which variability was confirmed, frequencies continued to be selected so long as their amplitude was > 4 times the average background of the pre-whitened residuals (Breger et al., 1993). Formal uncertainties on frequencies and amplitudes were obtained from the least-squares fitting using the method of Montgomery & O'Donoghue (1999).

Of the 1620 Am stars initially selected, a total of 227 (14% of the total) have been found to pulsate. The remaining 1393 stars were deemed as "not found to pulsate", since low-level pulsation could be present below the SuperWASP detection limits. Table 1 provides a summary of the pulsating Am stars. The individual periodograms and phase-folded lightcurves are presented in Fig. 1.

Table 2. Am stars with both SuperWASP and *Kepler* data.

KIC	Ren ID	Max Amp (mmag)	Ref
9204718	49340	0.13	Bal
11445913	49650	2.5	Cat,Bal
9272082	49840	<0.01	Bal
12253106	50070	<0.01	
9764965	50230	1.0	
8881697	50420	1.9	
11402951	50670	1.2	Cat,Bal
9349245	51233	<0.1	
8703413	51640	<0.1	Bal
8323104	52260	<0.1	Bal

Notes. The second column gives the identification number (Ren ID) from the Renson & Manfroid (2009) catalogue. Column 3 gives the amplitude (Max Amp) of the highest peak in the *Kepler* periodogram. Column 4 gives reference to published *Kepler* data: Cat: Catanzaro et al. (2011), Bal: Balona et al. (2011)

4. Stellar parameters

To place stars on the HR diagram we require values of $T_{\rm eff}$ and $\log L$. For stars with $uvby\beta$ photometry in the Hauck & Mermilliod (1998) catalogue, we used the UVBYBETA code of Moon (1985) to obtain de-reddened indices, and the $(b-y, c_0)$ grids of Smalley & Kupka (1997) to determine $T_{\rm eff}$ and $\log g$. For stars with only *uvby* photometry the above procedure was used but without the de-reddening step. For stars without *uvby* photometry, Geveva photometry from Rufener (1988) was used and the calibration of Künzli et al. (1997) used to determine $T_{\rm eff}$ and $\log g$, assuming zero reddening. In all of the above cases, the Torres et al. (2010) relations were used to determine $\log L$. For stars without suitable intermediate-band photometry, but with Hipparcos parallaxes (van Leeuwen, 2007), spectral energy distributions (SEDs) were constructed using literature broad-band photometry. Values of $T_{\rm eff}$ were determined by fitting Kurucz flux distributions to the SEDs and $\log L$ determined from the bolometric flux at the earth ($f_\oplus$) and the Hipparcos parallax. The typical uncertainties are estimated to be ±200 K in $T_{\rm eff}$ (±0.01 in $\log T_{\rm eff}$) and ±0.25 in $\log L$. The stellar parameters are given in Table 1. In total around a third of the Am stars investigated have stellar parameters determined.

5. Am stars in Kepler field

The sky coverage of the SuperWASP survey overlaps with a large fraction of the *Kepler* field. For Am stars with light curves in both the *Kepler* Public archive and the SuperWASP database we have compared the frequencies and amplitudes. This allows us to evaluate the detection limits of SuperWASP. Of the 10 stars with both *Kepler* and SuperWASP data, four have clear pulsations with amplitudes $\gtrsim$ 1 mmag (Table 2), while the other six stars have amplitudes below the SuperWASP detectability limit.

The PERIOD04 analysis (Table 3) shows good agreement above the nominal SuperWASP 1 mmag amplitude limit. There is a suggestion that the amplitudes found using SuperWASP lightcurves are slightly higher than those from *Kepler*. In addition, the SuperWASP frequency can differ from the 'true' frequency by a small integer number of 1 d^{-1} aliases. The comparison also shows that it is possible with SuperWASP data to detect frequencies slightly below the 1 mmag level (Figure 2). Naturally, the variable data quality of ground-based photometry means that not all stars with suitable variability will be detected.

Table 3. Comparison between frequencies and amplitudes found in the *Kepler* and SuperWASP data for the four Am stars common to both.

	Kepler		SuperWASP	
	Freq. (d^{-1})	Amp.[a] (mmag)	Freq. (d^{-1})	Amp. (mmag)
Ren ID 49650 (KIC 11445913, 1SWASP J190540.61+491820.7)				
f_1	31.5577 ± 0.0003	2.8	31.5577 ± 0.0001	3.2 ± 0.1
f_2	25.3799 ± 0.0007	1.1	25.3769 ± 0.0001	1.2 ± 0.1
f_3	22.1307 ± 0.0009	0.8	22.1306 ± 0.0002	1.0 ± 0.1
f_4	37.8182 ± 0.0011	0.6		
f_5	29.7394 ± 0.0012	0.6		
Ren ID 50230 (KIC 9764965, 1SWASP J191724.91+463535.2)				
f_1	27.1777 ± 0.0001	1.1	27.1778 ± 0.0001	1.2 ± 0.1
f_2	21.3819 ± 0.0002	0.6	22.3891 ± 0.0001	0.9 ± 0.1
f_3	31.9895 ± 0.0002	0.4	31.9902 ± 0.0001	0.9 ± 0.1
f_4	19.9579 ± 0.0004	0.2		
Ren ID 50420 (KIC 8881697, 1SWASP J192136.03+450706.8)				
f_1	16.5567 ± 0.0003	1.9	16.5565 ± 0.0005	2.1 ± 0.1
f_2	32.0477 ± 0.0004	1.5	32.0481 ± 0.0006	1.6 ± 0.1
f_3	25.2105 ± 0.0005	1.2	25.2064 ± 0.0008	1.2 ± 0.1
f_4	30.0120 ± 0.0006	1.1	30.0111 ± 0.0009	1.1 ± 0.1
f_5	34.3647 ± 0.0007	0.9	34.3661 ± 0.0009	1.0 ± 0.1
f_6	30.6537 ± 0.0008	0.9	30.6569 ± 0.0010	0.9 ± 0.1
f_7	28.8044 ± 0.0009	0.7	27.8049 ± 0.0011	0.8 ± 0.1
f_8	34.0106 ± 0.0009	0.7		
f_9	27.4073 ± 0.0010	0.7		
f_{10}	16.0119 ± 0.0013	0.5		
Ren ID 50670 (KIC 11402951, 1SWASP J192732.81+491523.5)				
f_1	23.8493 ± 0.0004	1.3	23.8464 ± 0.0008	1.4 ± 0.2
f_2	23.2770 ± 0.0004	1.1	23.2790 ± 0.0008	1.4 ± 0.2
f_3	27.4616 ± 0.0007	0.7	27.4643 ± 0.0012	1.0 ± 0.2
f_4	15.1001 ± 0.0007	0.7		
f_4	14.4967 ± 0.0009	0.5		

Notes. [(a)] Uncertainties on *Kepler* Amplitudes are all < 0.05 mmag.

6. Discussion

The pulsating Am stars (see Fig. 3) are concentrated within the fundamental radial mode red and blue edges of Dupret et al. (2005). This is in agreement with that found by Balona et al. (2011) for Am stars within the *Kepler* field. These studies show that pulsating Am stars are concentrated in the cooler region of the instability strip. Hot Am stars do not appear to pulsate at the precision of the *Kepler* data.

The standard interpretation of the Am phenomenon is that atomic diffusion – radiative levitation and gravitational settling – in the outer stellar envelope gives rise to the observed atmospheric abundance anomalies. For a typical mid-A star, $T_{\rm eff} \sim$ 8000 K, there are two thin convection zones in the outer envelope. The atmosphere itself is a convection zone a few thousand km thick where ionisation of H drives the convection. Deeper in the atmosphere, at $T \sim 50\,000$ K, the ionisation of He II also creates a thin convection zone, where the κ-mechanism drives δ Sct pulsation. It has long been clear that some Am stars and related types do pulsate, particularly the marginal Am stars (labelled spectroscopically as Am: stars), the evolved Am stars (δ Del or ρ Pup stars), and some more extreme cases, such as HD 188136 (Kurtz 1980; Wegner 1981) and HD 40765 (Kurtz et al., 1995).

The pulsation modes that we observe in Am stars are low radial order, low spherical degree p modes. The surface of the star is an anti-node. With the low radial order, the vertical wavelength is long compared to the depth of the envelope above the He II ionisation zone. With the decrease in density with height

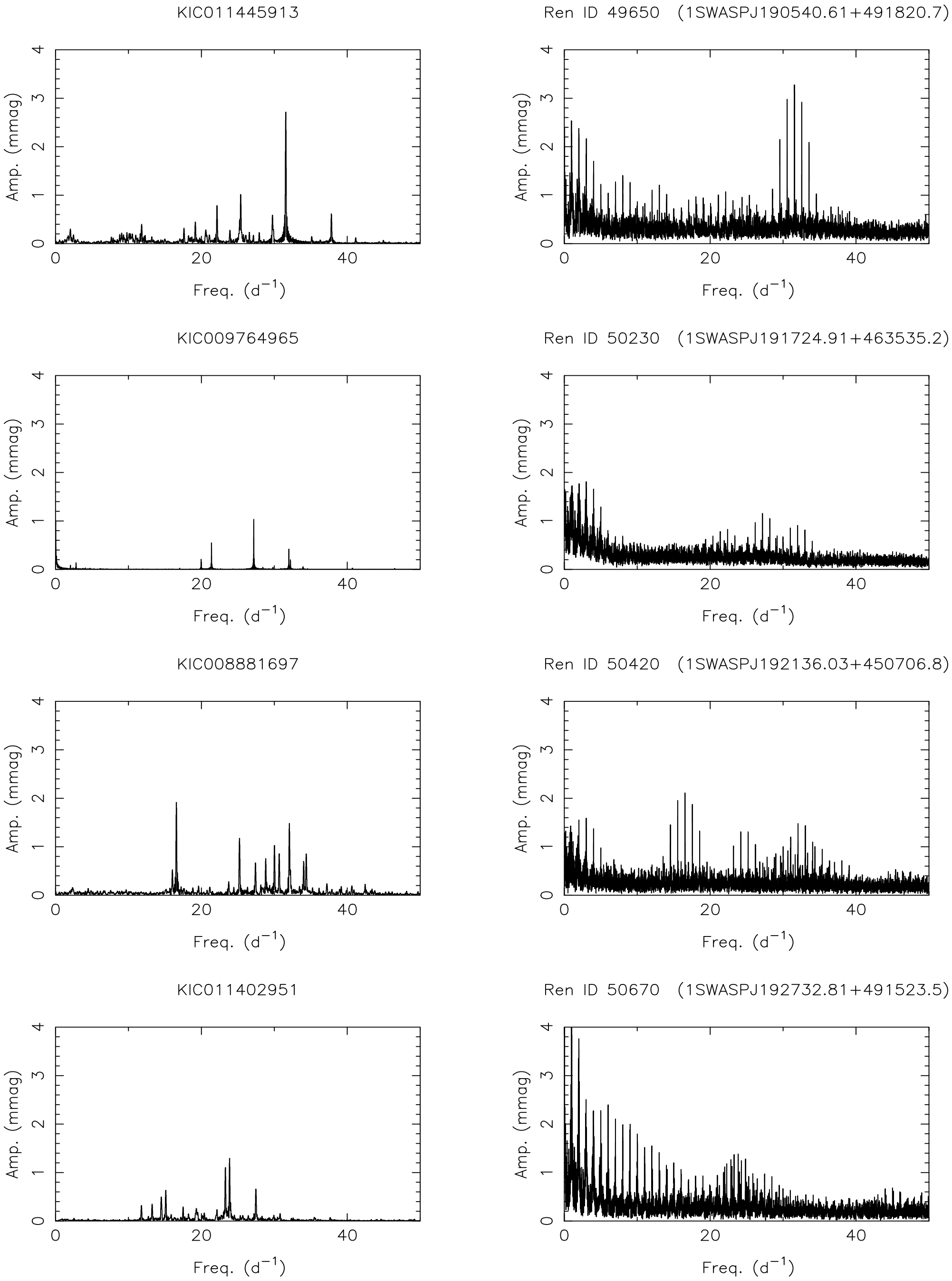

Fig. 2. Comparison between the PERIOD04 periodograms from *Kepler* (left) and SuperWASP (right) for four Am stars with pulsations detected by SuperWASP (see Table 3 for details of frequencies identified).

in the atmosphere, conservation of kinetic energy density means that the pulsation amplitude increases with height in the atmosphere, or conversely, decreases with depth.

In Am stars, the microturbulence velocity is also peculiar, as it is generally much higher than that of chemically normal stars. This high microturbulence arises from large velocity fields in the stellar atmosphere (Landstreet, 1998), which are even supersonic for some Am stars. We do not really know what causes these large velocity fields to develop exclusively in Am stars and how chemical peculiarities and velocity fields coexist. The results shown by Landstreet et al. (2009) suggest that there is a connection between $T_{\rm eff}$ and the velocity fields, peaking at around $T_{\rm eff} \sim 8000$ K, although we do not know what happens for cooler Am stars.

Atomic diffusion occurs in the radiative zone below the turbulent outer convective layer, which is far below the observable atmosphere. In this radiative layer there must be no turbulence at the diffusion velocity, which is of the order of 10^{-4} – 1 cm s^{-1}. The photometric amplitudes found in Am stars are consistent with atmospheric pulsation radial velocity amplitudes of a few km s^{-1}. Taking into account the decrease in pulsation amplitude with depth –largely because of the increase in density, but also because of the radial wave function – the pulsation velocity in the radiative layer where atomic diffusion is most important in Am stars is still of the order of a km s^{-1}. With such pulsations in

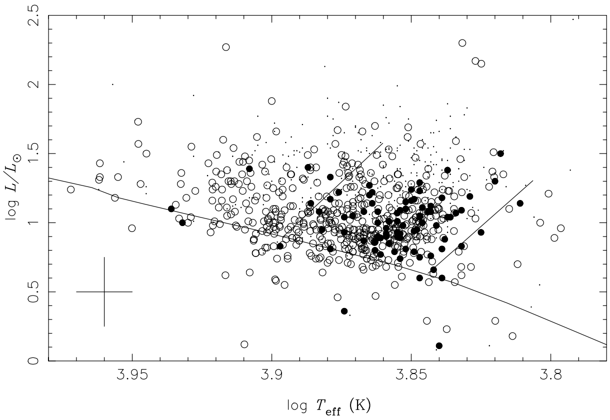

Fig. 3. HR diagram showing the location of Am stars. The filled circles are the Am stars which were found to pulsate, while the open circles are the Am stars which were not found to pulsate. The solid lines indicate the location of the ZAMS and the fundamental radial mode red and blue edges of the instability strip (Dupret et al., 2005). The large cross indicates the typical uncertainties in $\log T_{\rm eff}$ and $\log L$. The dots are the δ Sct stars from the catalogue of Rodríguez et al. (2000).

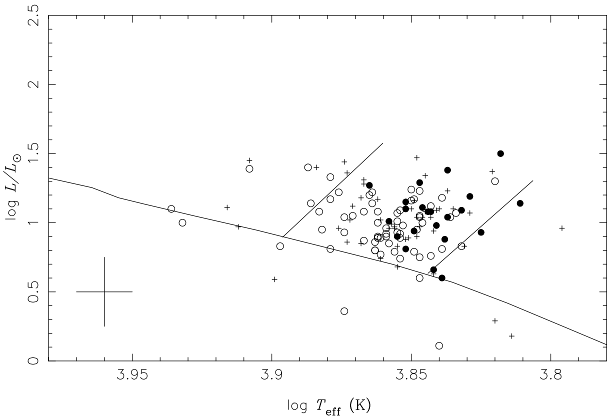

Fig. 4. Location of the pulsating Am stars in the HR diagram. The circles are pulsating Am stars, with the filled circles indicating those with spectral classification noted as δ Del. The crosses are the Fm δ Del stars which were not found to pulsate. The solid lines indicate the location of the ZAMS and the fundamental radial mode red and blue edges of the instability strip (Dupret et al., 2005). The large cross indicates the typical uncertainties in $\log T_{\rm eff}$ and $\log L$

a layer where atomic diffusion is operating at sub-cm s^{-1} velocities, it must be that the pulsation is laminar; i.e., producing no turbulence at the sub-cm s^{-1} level.

With the results from the *Kepler* mission (Balona et al., 2011) and now our results from SuperWASP we conclude that the loss of helium by gravitational settling from the He II ionisation zone reduces driving, but does not suppress it entirely. Thus Am stars can pulsate as δ Sct stars, but typically with relatively low amplitudes compared to normal abundance δ Sct stars. Some Am stars show no pulsation whatsoever at *Kepler* μmag precision. It has yet to be shown whether this lack of pulsation can also occur in the more rapidly rotating normal abundance stars in the δ Sct instability strip. Study of this question is in progress with *Kepler* data. As was concluded for the individual cases of HD 188136 and HD 40765, we may now state in general: in Am stars the pulsation must be laminar, not generating turbulence to mix away the observed effects of atomic diffusion in the outer atmosphere.

The Fm δ Del subclass are evolved Am stars above the main-sequence, many of which have been found to show variability (Kurtz, 1976). Not unexpectedly, many stars classed as Fm δ Del are found to be pulsating in the WASP data, but clearly not all. Of the 227 Am stars that we found to be pulsating 55 are classed as Fm δ Del: 24% of the Am stars found to pulsate. This compares to a total of 186 Fm δ Del stars out of the 1620 Am stars investigated using WASP data, around 11% of the sample. Therefore, 30% of the Fm δ Del stars have been found to pulsate, compared to just 12% of other Am stars. Thus pulsation amplitude either grows in Am stars as they evolve, or some non-pulsating Am stars begin pulsating as they move off the main sequence. This is likely to be a consequence of the driving region moving deeper into the star where the helium abundance is higher than in the main sequence He II ionisation zone (see Turcotte et al. 2000 for theoretical discussion).

The location of the pulsating Fm δ Del stars in the HR diagram is shown in Fig. 4. There is a tendency for the pulsating Fm δ Del stars to be located toward the cooler (and/or) slightly more evolved parts of the instability strip, whereas the non-pulsating Fm δ Del stars are distributed more uniformly. The frequency–amplitude diagram (Fig. 5) shows that the Fm δ Del stars occupy the same regions as the other Am stars, but with an absence of high-frequency ($\gtrsim 20\,{\rm d}^{-1}$) pulsations; this is not surprising, given that they are cooler and more evolved than average δ Sct stars.

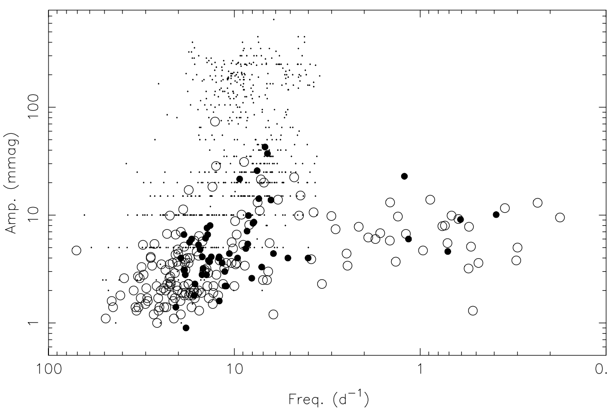

Fig. 5. Frequency-amplitude diagram for pulsating Am stars shown as circles, with filled circles indicating those with spectral classification noted as δ Del. Note that in multi-periodic systems only the frequency of the highest amplitude is shown, as given in Table 1. The dots are the δ Sct stars from the catalogue of Rodríguez et al. (2000).

Several factors are thought to play a role in the development of pulsating Am stars, but stellar rotation is probably one of the most important. Charbonneau & Michaud (1991) showed that Am chemical peculiarity develops in stars that rotate slower than 90 km s^{-1} and that the He II ionisation zone deepens with decreasing rotation. This was later confirmed by more advanced diffusion model calculations by Talon et al. (2006) and observationally by Fossati et al. (2008), who found a correlation between Am chemical peculiarities and $v \sin i$ in Am stars belonging to the Praesepe open cluster. The vast majority of the Am stars already known to pulsate have a rather large $v \sin i$, between 40 and 90 km s^{-1}, thus avoiding the He II ionisation zone sinking too deep into the star and therefore allowing the development of pulsation driven by the κ-mechanism. On the other hand, for the very slowly rotating pulsating Am stars, the pulsation could be laminar. It is therefore likely there are two different mechanisms driving pulsation in Am stars.

Our results show a wide variety of pulsations, from singly periodic to complex multiperiodic, and also some examples of what appear to be hybrid γ Dor/δ Sct pulsators. This is similar to the range of behaviour seen in normal abundance δ Sct stars, as can be seen in the study of *Kepler* data by Grigahcène et al. (2010). Those authors reclassified pulsation types with the following scheme:

- **δ Sct:** frequencies above 5 d^{-1};
- **δ Sct/γ Dor hybrid:** most frequencies above 5 d^{-1}, but some low frequencies present;
- **γ Dor:** frequencies lower than 5 d^{-1};
- **γ Dor/δ Sct hybrid:** most frequencies lower than 5 d^{-1}, but some high frequencies present.

Our results are summarized in Table 4 and the individual classes for each star are given in Table 1. The majority of the pulsators we found are δ Sct stars, with the remaining quarter split between γ Dor stars and mostly δ Sct/γ Dor hybrids. Given that the SuperWASP data are affected by daily aliases and systematics at low frequencies, the true number of stars with γ Dor pulsations may indeed be higher. However, given that Am stars are thought to be members of binary systems and tidal effects slow the stellar rotation rate, it is possible that some of the low-frequency signatures found in the SuperWASP data are due to ellipsoidal effects in close binaries. Assuming a rotation limit of $v \sin i \lesssim 120\,\mathrm{km\,s^{-1}}$ for an Am star and a radius of $1.5\,R_{\odot}$, the shortest period for a binary system containing a tidally-synchronised Am star is ~0.6 d. Close binary systems with dissimilar components have two maxima and minima per orbital period, and this value dominates over the orbital value in periodograms. Hence, frequencies $\lesssim 3.3\,\mathrm{d}^{-1}$ may have arisen due to ellipsoidal variations in close binaries. Thus, we caution that some of the stars presented in Table 1 could have erroneously been classified as having γ Dor pulsations. In addition, it is possible that long-period pulsations in close binaries could be tidally excited (Handler et al., 2002).

It is clear from examination of the *Kepler* data set that the δ Sct stars show frequencies ranging from nearly zero d^{-1} up to 100 d^{-1}; some stars even show the full range, including frequencies between the g mode and p mode ranges seen in models. These intermediate frequencies are unexplained at present. It is clear that the δ Sct stars are complex pulsators that show g modes, p modes, mixed modes and many nonlinear cross terms. Whether there are differences between abnormal abundance, slowly rotating Am stars that are δ Sct stars and the more rapidly rotating, normal abundance δ Sct stars is yet to be determined. The objects we present here from SuperWASP greatly increases the number of pulsating Am stars for statistical study of this question.

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Table 4. The number of pulsating Am stars and percentage in each of the four pulsation classes as defined by Grigahcène et al. (2010).

Pulsation Class	Number	Percentage
δ Sct	169	75
δ Sct/γ Dor	23	10
γ Dor	30	13
γ Dor/δ Sct	5	2

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Table 1. Pulsating Am stars.

Ren ID	Name	Sp. Type	$\log T_{\rm eff}$ (K)	$\log L$ ($L_\odot$)	Method	Freq. (d^{-1})	Amp. (mmag)	nFreq.	ΔT (d)	Class
10	HD 154A	A9mF2	3.862	0.89	a	4.7672	22.4	2	1135	γ Dor
110	HD 719	A3mF0	3.855	1.01	a	14.1368	3.2	10	473	δ Sct
113	HD 728	A m δ Del				14.9268	2.8	2	119	δ Sct
140	HD 923	A6mF2	3.908	1.39	a	18.6684	2.2	1	50	δ Sct
210	HD 1097	A4mF4 Sr	3.840	0.11	a	15.5491	2.0	2	50	δ Sct
355	HD 1651	A6mA9	3.859	0.92	a	15.0600	1.9	8	154	δ Sct
500	BD+40 77 A	A2mA7 Sr				32.3130	2.6	10	146	δ Sct
1233	HD 4630	A3m δ Del				20.6497	1.4	1	114	δ Sct
1790	HD 7133	A3 Sr or Am δ Del ?	3.832	1.09	a	14.8755	4.1	8	114	δ Sct
1830	CD-22 422	A6m				1.9041	6.2	4	140	γ Dor
1920	TYC 5276-1653-1	A6m				1.6420	6.8	5	140	δ Sct/γ Dor
1984	HD 8043	A2mF	3.849	1.17	a	10.3662	3.6	1	115	δ Sct
2060	HD 8457	A2mF				16.5741	1.9	7	140	δ Sct
2340	BD-12 290	A2mA7	3.862	1.08	b	34.8219	2.0	6	136	δ Sct
2370	HD 9659	A1mA7	3.883	1.08	c	17.6028	17.1	8	927	δ Sct
2720	BD+58 304	A7m				28.1912	4.0	6	115	δ Sct
2920	HD 11490	A5m	3.859	0.96	a	6.1679	1.2	7	580	δ Sct
3013	TYC 2816-327-1	F1mF4	3.832	0.83	a	0.8838	13.9	2	1246	γ Dor
3340	HD 12961	A5mF3 δ Del?				4.0115	4.0	7	563	δ Sct/γ Dor
3378	HD 13079	F0m	3.854	0.74	a	19.4090	7.0	5	480	δ Sct
3550	HD 13776	A0m	3.862	0.90	d	4.4078	15.2	2	563	γ Dor
3655	HD 14494	A5mA9	3.850	1.16	a	15.5855	4.2	10	910	δ Sct
4413		A3m	3.839	0.81	a	21.3019	1.6	7	511	γ Dor/δ Sct
4793	HD 19108	A3m δ Del	3.852	0.81	a	14.7306	3.2	5	121	δ Sct
4885	HD 19762	A5mA8				16.9993	1.4	1	145	δ Sct
5055	HD 20308	A5mF0	3.864	1.14	d	29.7634	2.1	4	521	δ Sct
6044	HD 23543	A5m δ Del				7.1268	3.3	3	521	δ Sct
6083	TYC 3729-775-1	A2mF0				24.0686	2.1	1	94	δ Sct
6295	TYC 3725-169-1	A3m				28.1774	4.1	2	1228	δ Sct
6390	HD 25052	A7m	3.853	0.98	a	6.5758	3.0	7	521	δ Sct/γ Dor
6368	HD 24925	A5m δ Del?				18.2088	0.9	1	119	δ Sct
6463	HD 25369	A2mA8				31.8867	1.7	4	119	δ Sct
6527	HD 25648	A1m	3.865	1.20	d	1.3183	9.7	1	112	γ Dor
6681	HD 26386	A3mF0				20.7307	4.3	7	134	δ Sct
6663	TYC 3726-618-1	A2mF0				22.3602	2.6	1	71	δ Sct
8720	HD 34296	A3mF2	3.861	0.77	a	1.7424	6.0	9	506	δ Sct/γ Dor
8711	HD 242159	A5m				8.7898	3.4	8	1233	δ Sct
8842	HD 242632A	A5m				0.3043	3.8	1	924	γ Dor
8898	HD 34841	A2m	3.886	1.14	a	11.4943	2.3	4	139	δ Sct
8932	HD 242938	A5m				21.6154	1.8	3	902	δ Sct
8951	HD 243010	A3m				16.4353	2.0	2	927	δ Sct
8972	HD 243093	A5m				19.9969	3.4	6	1232	δ Sct
8974	HD 243112	A2m				44.9530	1.4	2	139	δ Sct
8988	HD 35236	A2m				45.7112	1.6	2	139	δ Sct
9084	HD 35467	A2m				33.0007	2.7	3	1233	δ Sct
9123	HD 243542	A3m				25.6983	1.7	2	1233	δ Sct
9144	HD 35531	A2m				21.4997	3.6	5	1232	δ Sct
9262	HD 244020	A7m				6.4681	5.5	2	1200	δ Sct
9269		A3m				9.7183	3.6	2	138	δ Sct
9470	BD-7 1108	A6mF2	3.854	1.09	a	12.7088	73.6	4	112	δ Sct
9375	TYC 2411-1663-1	A5m				21.9980	2.4	5	941	δ Sct
9454	HD 244698	A2m				29.4675	1.7	2	133	δ Sct
9685	HD 36887	F0m δ Del?	3.855	0.90	a	0.7113	4.6	2	152	γ Dor
9534	HD 244810	A3m				18.5025	3.6	4	941	δ Sct
9581	HD 36681	A2m	3.858	0.85	a	20.8887	1.7	1	139	δ Sct
9556	BD+34 1091	A0m				1.4571	5.8	1	941	γ Dor
9653	HD 245063	A3m				11.0583	3.6	1	941	δ Sct
9812	HD 245303	A3m				17.6418	3.6	5	138	δ Sct
9868		A3m				0.6786	9.9	3	152	γ Dor
10206	TYC 1869-592-1	A5m				23.4739	3.1	1	133	δ Sct
10259	HD 246984	A5m				20.7162	6.6	3	935	δ Sct
10383	HD 247634	A7m				2.8538	7.4	3	928	γ Dor
10423	HD 247837	A1m				0.2336	13.0	2	923	γ Dor
10610	HD 39641	A5mF1	3.863	0.86	a	20.4628	2.2	8	177	δ Sct/γ Dor
10448	HD 248069	A0m				3.7473	10.6	2	923	γ Dor/δ Sct
10474	HD 248174	A2m				18.3207	1.9	1	133	δ Sct

Table 1. continued.

Ren ID	Name	Sp. Type	$\log T_{\rm eff}$ (K)	$\log L$ ($L_{\odot}$)	Method	Freq. (d^{-1})	Amp. (mmag)	nFreq.	ΔT (d)	Class
10482	HD 248244	A1m				49.2363	1.1	1	138	δ Sct
10565	HD 248637	A2m				12.4952	2.8	5	133	δ Sct
10554	HD 248577	A0m				11.3345	3.2	1	1194	δ Sct
10586	TYC 1867-814-1	A5m				12.5497	28.5	5	923	δ Sct/γ Dor
10602	HD 248874	A0m				0.1771	9.5	1	138	γ Dor
10641	HD 249278	A5m				29.2307	1.6	1	138	δ Sct
10855	TYC 1876-325-1	A0m				9.9108	8.8	1	138	δ Sct
11007	HD 251038	A0m				14.3993	3.1	3	1915	δ Sct
11022	HD 251095	A2m				7.3109	11.0	6	1218	δ Sct
11025	HD 251143	A3m				17.2563	1.9	3	133	δ Sct
11032	HD 251227	A3m				3.8590	3.9	4	133	δ Sct/γ Dor
11033	HD 251226	A5m				22.1084	2.7	2	133	δ Sct
11135	HD 251963	A7m				10.1655	4.9	4	1218	δ Sct
11184	HD 252154	A5m				1.4525	13.1	5	919	δ Sct/γ Dor
11182	TYC 1889-117-1	A3m				6.6767	2.5	1	133	δ Sct
11274	HD 252679	A3mF2				30.1049	1.5	2	138	δ Sct
11265	HD 42155	A2m				22.0073	2.3	4	133	δ Sct
11473	TYC 1314-887-1	A3mF2				1.1943	6.7	1	138	γ Dor
11820	HD 44596	A6mF2	3.847	1.04	a	11.9914	3.8	15	177	δ Sct
12250	HD 45863	A2mA8	3.879	0.81	c	0.5209	1.3	1	1040	γ Dor
12820	HD 47743	A3mF0	3.863	0.80	a	18.3705	3.9	3	66	γ Dor/δ Sct
12940	HD 48223	A4m δ Del?				18.5331	3.1	13	795	δ Sct/γ Dor
13550	CP-60 704	F0m				14.5060	3.0	9	177	δ Sct
14140	HD 51319	A2mA9				15.9002	1.9	5	177	δ Sct
15423	HD 56484	A2mF0	3.876	1.22	a	14.8533	5.7	3	132	δ Sct
16920	HD 61659	A5mF0	3.874	0.93	a	0.7136	5.5	1	142	γ Dor
18657	HD 67518	A3m δ Del	3.841	0.98	a	5.1544	4.0	2	117	δ Sct/γ Dor
18730	HD 67911	F0mF4	3.834	1.07	a	8.8671	31.1	3	98	δ Sct
20143	HD 72658	F m δ Del?				8.6775	4.9	1	96	δ Sct
20333	HD 73144	F m δ Del?				8.0629	2.6	1	97	δ Sct
20485	HD 73675	A4m				33.6236	1.3	4	96	δ Sct
20855	HD 74626	A5m δ Del				7.8486	8.6	10	119	δ Sct
20908	HD 74784	A3mF2 δ Del?	3.837	1.38	a	7.5427	25.8	12	97	δ Sct
21730	HD 77105	A3m Sr δ Del	3.829	1.19	d	11.2579	3.0	6	119	δ Sct
21920	HD 77532	A5mF0				19.5074	1.6	4	119	δ Sct
22180	HD 78325	A2mA8				7.0172	2.5	5	717	δ Sct/γ Dor
22404	HD 79034A	F0m δ Del				14.3002	6.1	2	96	δ Sct
22450	HD 79111	A2mF2				15.9320	4.6	1	745	δ Sct
22685	HD 79787	A3mF2				20.9176	2.9	4	749	δ Sct
23195	HD 81729	A5m	3.850	1.24	d	9.7198	6.6	4	131	δ Sct
23410	HD 82396	F0m δ Del	3.847	1.29	a	9.3672	21.6	6	110	δ Sct
23672	HD 83049	F5m δ Del				7.3912	14.2	3	511	δ Sct
24920	HD 87118	A4mF2				0.5334	5.1	1	521	γ Dor
24990	HD 87360	F0m δ Del	3.865	1.27	a	13.5113	8.0	2	457	δ Sct
25160	HD 87869	A2m δ Del				13.8008	3.8	7	113	δ Sct
25730	BD+42 2113	A mF				8.3255	8.1	2	134	δ Sct
26360	HD 91616	A3mF3				0.4861	3.6	1	717	γ Dor
26860	HD 93038	A3m				17.9074	4.0	7	717	δ Sct/γ Dor
26880	HD 93137	F5m δ Del				6.6384	37.2	7	1090	δ Sct
27270	HD 94479	A4mF0	3.862	1.00	a	20.1477	4.8	3	123	δ Sct
27405	HD 95192	A1mF0				19.0772	1.9	2	478	δ Sct
27526	HD 95562	A2mA9	3.871	1.05	d	41.0464	1.8	1	144	δ Sct
27610	HD 95856	F5m δ Del	3.843	1.08	a	17.4329	5.6	6	510	δ Sct
28290	HD 98009	A3mF0				34.0300	1.4	5	510	δ Sct
28340	HD 98299	A3mA7				13.0735	1.5	2	144	δ Sct
28510	HD 98946	A5m	3.887	1.40	a	18.6186	5.1	3	1097	δ Sct
28610	HD 99302	A3mF1	3.882	0.95	b	39.1743	2.6	2	134	δ Sct
28690	HD 99729	F5m δ Del	3.825	0.93	d	7.9438	8.4	9	510	δ Sct
28850	HD 100376	F0m δ Del?				1.2169	22.9	3	510	γ Dor
29280	BD+41 2224	A0m				0.3505	11.6	2	1108	γ Dor
29310	HD 101717	A5m δ Del				18.3663	2.8	2	142	δ Sct
29590	HD 102594	F2m δ Del				16.3003	2.3	9	414	δ Sct
29800	HD 103318	A4m				16.3386	1.7	2	132	δ Sct
30390	HD 104957	A3mF1	3.867	0.87	a	18.8594	11.3	6	409	γ Dor/δ Sct
30453	BD+18 2569	A m	3.847	0.75	a	16.8163	1.8	5	1058	δ Sct
30926	HD 106832A	A1mA9 Hg				23.3836	2.0	1	496	δ Sct

Table 1. continued.

Ren ID	Name	Sp. Type	$\log T_{\rm eff}$ (K)	$\log L$ ($L_\odot$)	Method	Freq. (d^{-1})	Amp. (mmag)	nFreq.	ΔT (d)	Class
30970	TYC 2530-1366-1	A2m				10.0009	2.2	1	1108	δ Sct
31500	HD 108452	A0m				70.7600	4.7	7	117	δ Sct/γ Dor
31560	HD 108668	A3mF2				23.2410	1.4	1	153	δ Sct
31600	BD+37 2284	A7mF3	3.879	1.17	a	22.2298	9.9	8	1123	δ Sct/γ Dor
31680		A5m	3.874	1.04	b	2.1429	7.8	4	1123	δ Sct/γ Dor
31710	HD 109306	F2m	3.836	1.04	a	3.0068	9.8	3	136	δ Sct/γ Dor
31800	TYC 2533-2112-1	A2m				24.6919	3.5	1	136	δ Sct
31913	HD 109957	A3m δ Del	3.839	0.60	d	13.3080	4.1	2	509	δ Sct
31950	HD 110056	A3mF0	3.847	0.60	d	16.4269	5.8	10	755	δ Sct
32180	BD+38 2361	A6mF2	3.864	1.22	a	20.0646	4.4	3	1123	δ Sct
32340	BD+21 2457	A3m	3.847	1.05	a	13.1200	18.3	8	136	δ Sct
32624	HD 112340	A2m	3.936	1.10	a	31.0376	5.3	3	779	δ Sct
32870	HD 113221	A3mF0	3.854	0.89	c	25.5893	1.3	2	713	δ Sct
32885	HD 113385	F0m δ Del	3.842	0.66	a	0.3905	10.1	5	483	γ Dor
33220	HD 114839	A3m	3.863	0.80	a	0.9665	4.7	9	1080	δ Sct/γ Dor
33490	HD 115800A	F5m δ Del				6.1654	4.4	1	167	δ Sct
33555	HD 116276	F0m δ Del	3.846	1.11	a	10.6404	4.4	6	1141	δ Sct
33636	HD 116635	A2m	3.932	1.00	a	0.2997	5.0	2	136	γ Dor
33940	HD 117682	F5m δ Del				13.9189	6.6	11	713	δ Sct
34137	BD+35 2465	A m	3.897	0.83	a	0.7607	7.9	1	1138	γ Dor
34076	HD 118209	A3mF3				17.6727	2.3	7	396	δ Sct
34620	HD 120054	A2mA8				1.3539	3.7	2	713	γ Dor/δ Sct
34930	HD 121352	A4mF3				15.4849	6.4	2	483	δ Sct
34920	HD 121290	A2mA9				0.7363	8.0	1	755	γ Dor
34996	HD 121698	A4mF2				0.5498	3.2	1	143	γ Dor
35074	HD 122370	F0m δ Del	3.849	0.94	a	15.5955	5.3	2	489	δ Sct
35450	HD 123937	F2m δ Del?				6.8438	42.8	11	714	δ Sct
35490	HD 124028	F2m δ Del?				11.0526	2.2	1	752	δ Sct
35650	HD 124467	A2mF2				26.8987	5.4	5	752	δ Sct
35710	HD 124891	A3m δ Del				1.1567	6.0	2	714	γ Dor
35776	HD 125296	A4mF0				20.2108	2.0	2	143	δ Sct/γ Dor
36080	HD 126685	A5mF2				17.3456	4.0	3	755	δ Sct
36330	HD 127832	F5m δ Del				8.4714	5.4	5	752	δ Sct
36940	HD 129570	A2mF0				26.1936	2.2	3	153	δ Sct
37513	HD 132092	A5mF0	3.862	0.89	a	18.3348	3.1	4	464	δ Sct
37494	HD 132054	A3mA9				17.5428	1.8	1	890	δ Sct
37884	HD 133489	A2m δ Del				9.6097	4.0	8	1178	δ Sct
38400	HD 135306	F5m δ Del				12.1156	4.0	7	753	δ Sct
40280	HD 141976	A6m				22.3807	2.2	4	167	δ Sct
40613	HD 143439	F0m δ Del	3.852	1.10	a	14.1303	2.8	5	1192	δ Sct
40675	HD 143517	A3 Sr or δ Del				14.0384	7.6	18	1192	δ Sct/γ Dor
40805	HD 144033	A3mF4	3.779	2.72	b	15.4669	1.3	2	391	δ Sct
41030	HD 144768	A5m δ Del				16.9885	6.0	2	657	δ Sct
41315	HD 146053	A6mF3				9.8533	3.5	14	1192	δ Sct/γ Dor
41640	HD 147400	A2mF3				12.2295	1.8	6	755	δ Sct
43588	HD 154225	A5m	3.820	1.30	b	6.9346	20.0	4	1047	δ Sct
43590	HD 154226	A2m	3.879	1.33	d	0.6233	9.2	1	127	γ Dor
45870	BD+46 2371	A3m	3.861	0.89	a	32.7894	1.4	5	126	δ Sct
46050	BD+45 2607	A3m				13.7280	1.7	4	126	δ Sct
49650	HD 178327	A6mF5	3.859	0.90	b	31.5577	3.3	3	456	δ Sct
50230	HD 181206	A5m				27.1776	1.2	3	128	δ Sct
50420	BD+44 3115	A5m				16.5565	2.1	7	128	δ Sct
50670	HD 183489	A9mF5	3.855	1.07	b	23.8464	1.4	3	1562	δ Sct
50520	HD 182684	A7m δ Del?				12.1003	4.0	12	519	δ Sct
51760	HD 187698	A3mF0				0.5468	7.8	1	755	γ Dor
52850	HD 190242	A1mF2	3.854	0.92	c	26.0473	1.0	2	755	δ Sct
54150	HD 193981	A6m				24.8629	2.0	8	162	δ Sct
54515	HD 195638	F2m δ Del	3.811	1.14	d	8.4041	9.9	1	124	δ Sct
54656	HD 196100	A3mA9				27.7231	3.4	2	890	δ Sct
54736	HD 196414	A3m δ Del	3.838	0.88	d	11.2288	2.2	3	890	δ Sct
54970	HD 197105	A5m	3.856	0.79	a	7.5023	13.1	2	832	δ Sct
55087	HD 235334	A mF				8.9589	5.3	3	135	δ Sct
55094	HD 197778	A2m δ Del?				15.2904	4.8	4	105	δ Sct
55710	HD 200057	A4mF δ Del				18.6734	6.6	10	907	δ Sct
56159	BD+37 4187	A5m				12.9635	2.2	6	125	δ Sct
56110	HD 201150A	A3mF0	3.843	0.76	c	17.6571	2.3	2	907	δ Sct

Table 1. continued.

Ren ID	Name	Sp. Type	$\log T_{\rm eff}$ (K)	$\log L$ ($L_\odot$)	Method	Freq. (d^{-1})	Amp. (mmag)	nFreq.	ΔT (d)	Class
56275	BD+34 4321	A7 Si Sr or A5m				5.8258	13.9	7	125	δ Sct
56280	HD 201816	A3mF0	3.874	0.36	d	22.2879	3.5	3	179	δ Sct
56770	HD 203880	A5mA9	3.848	0.95	c	12.9823	1.9	4	179	δ Sct
56980	HD 204620	A9m				10.3385	5.6	3	537	δ Sct
57020	HD 204806	A4mF1				2.4913	4.4	4	536	δ Sct/γ Dor
57104	HD 204972	A2mF2	3.849	0.79	d	13.8158	2.9	4	1219	δ Sct
57300	HD 205651	A4mF3 δ Del?				11.6332	3.6	13	536	δ Sct
57323	HD 205813	F0m δ Del	3.858	1.01	a	16.4598	1.8	4	141	δ Sct/γ Dor
57696	TYC 3975-745-1	A5m				13.9770	2.2	5	140	δ Sct
57760	HD 207658	A5m δ Del?				19.3944	4.0	8	537	δ Sct
57764	HD 207723	A1mF3				30.8011	2.8	4	439	δ Sct
58270	HD 209430A	A2mF2	3.839	1.18	c	22.9653	2.3	5	556	δ Sct
58440	HD 209930	A3m δ Del	3.844	1.08	a	13.5892	3.7	1	179	δ Sct
58850	HD 212108	A2m	3.867	1.08	d	19.4303	1.2	4	112	δ Sct
58870	HD 212164	A1mA9				2.4622	3.4	5	556	δ Sct/γ Dor
59072	TYC 3611-1607-1	A3m				4.4864	9.9	2	120	γ Dor
59020	HD 212765	A2mF2				23.0318	6.7	8	556	δ Sct
59090	HD 213204	F1m	3.843	1.12	a	9.1521	10.1	4	549	δ Sct
59500	HD 215396	A2mF3	3.846	1.00	c	18.5845	1.8	5	555	δ Sct
59560	HD 215611	A8mF3 δ Del	3.852	1.15	a	6.3584	13.8	4	1218	δ Sct
60696	HD 221446	F2m δ Del				12.0775	4.1	3	141	δ Sct
60690	HD 221431	A5m δ Del	3.837	1.04	b	0.6072	9.1	2	563	γ Dor
60740	HD 221576	A2m				25.3063	1.4	1	506	δ Sct
61105	HD 222828	F2m δ Del	3.818	1.50	b	8.5454	7.1	2	546	δ Sct
61320	HD 223676	A2mA8	3.855	0.93	c	21.1612	1.1	1	563	δ Sct
61350	BD+44 4512	A2mF5				3.3802	2.3	1	140	γ Dor
61356	HD 223944	A7mF4				7.1976	21.4	6	154	δ Sct
61580	HD 224657	F0mF5	3.847	1.23	b	20.3278	3.7	2	140	δ Sct
61756	HD 225184	A2m δ Del				12.0588	1.6	7	520	δ Sct

Notes. The first column gives the identification number (Ren ID) from the Renson & Manfroid (2009) catalogue. In column 6, the method of stellar parameter determination is given: a) *uvbyβ* photometry, b) *uvby* photometry c) Geneva photometry, d) spectral energy distribution and parallax. Freq. is the frequency of the highest amplitude (Amp.) and nFreq is the number of identified frequencies. ΔT is the time baseline of the SuperWASP photometry. Class is the pulsation class as defined by Grigahcène et al. (2010).

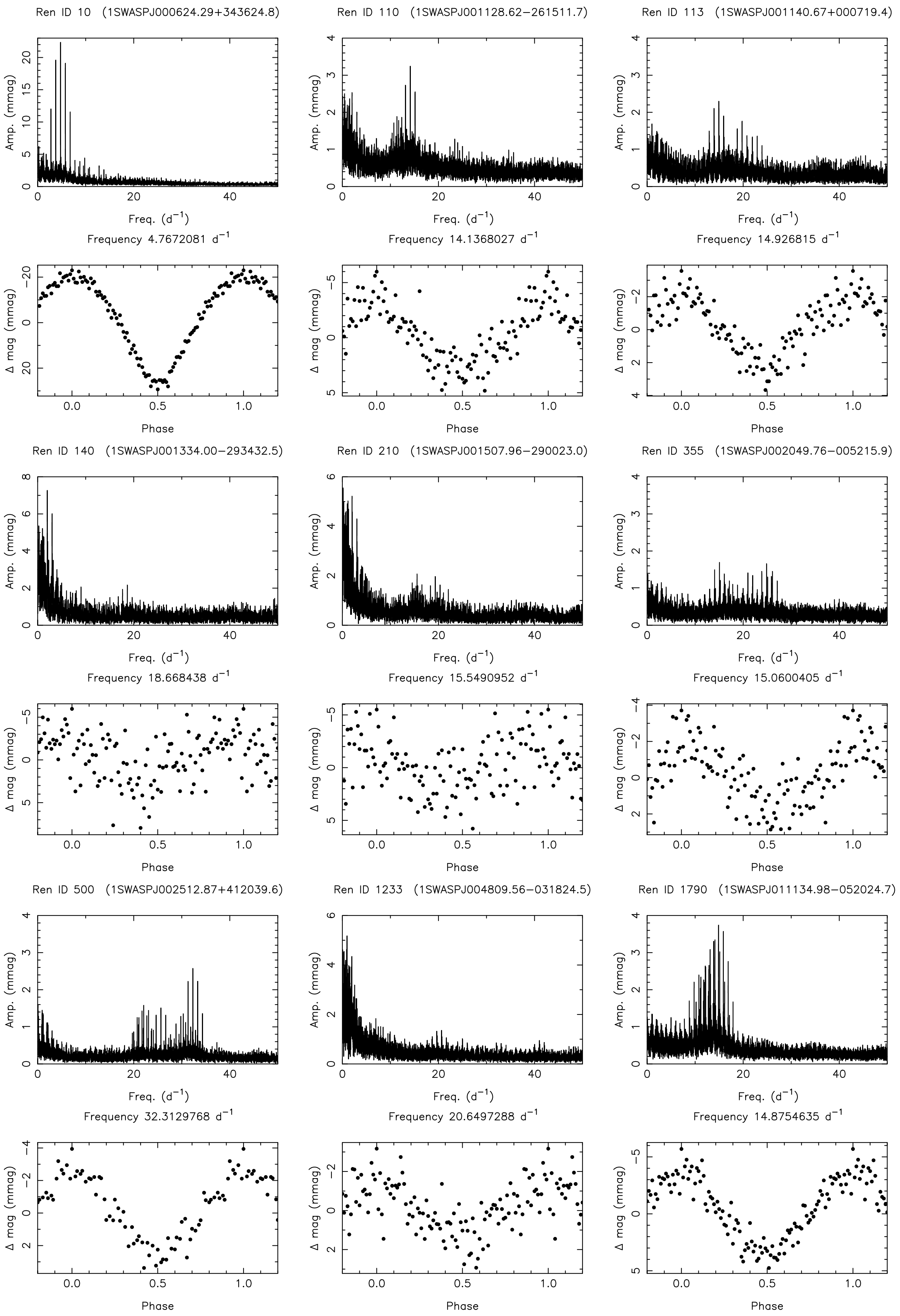
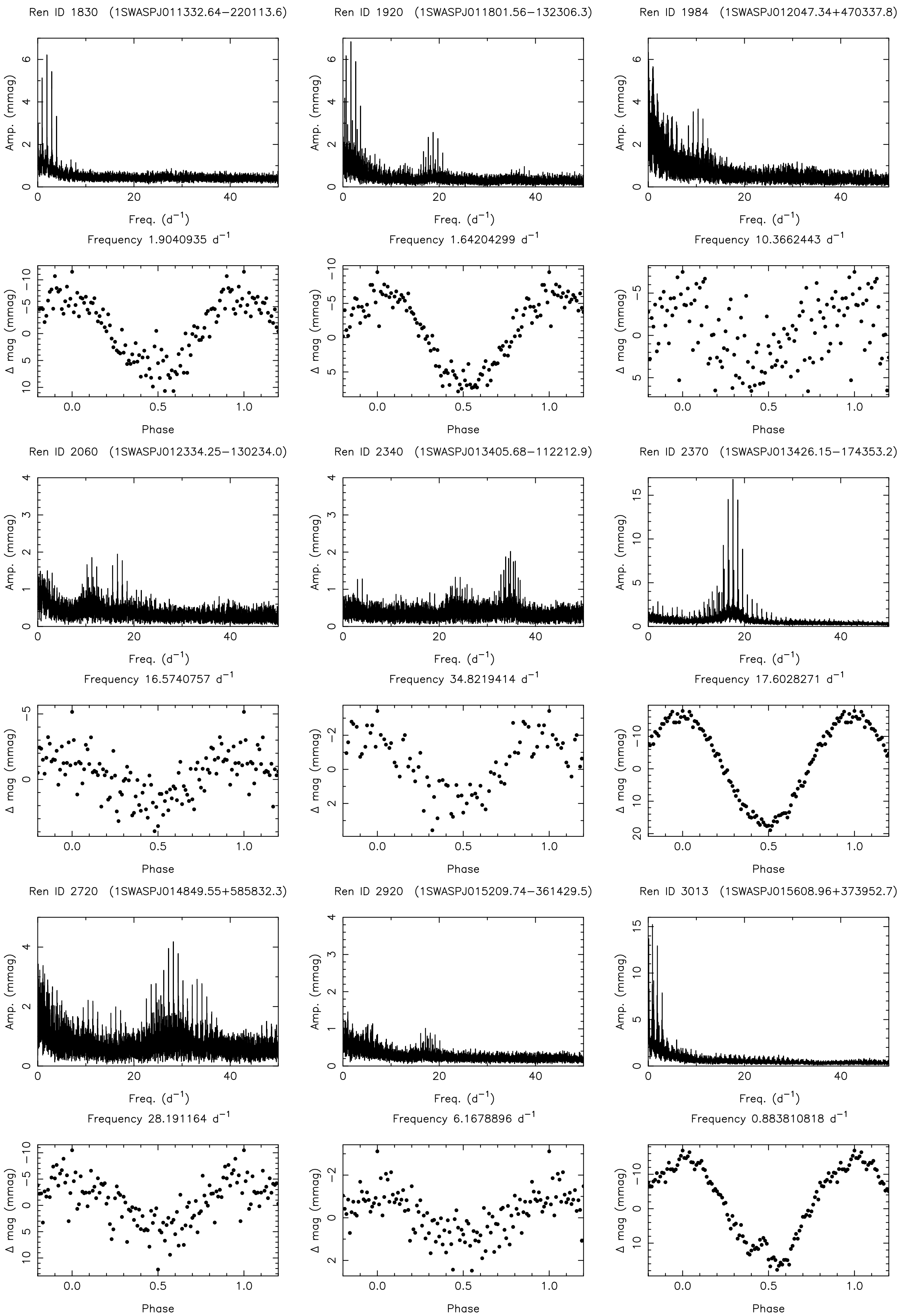


Fig. 1. SuperWASP periodograms for the pulsating Am stars (top) and corresponding lightcurves folded on the principal frequency (below). The lightcurves have been binned in 0.01 phase steps and phase 0.0 corresponds to the time of maximum light.



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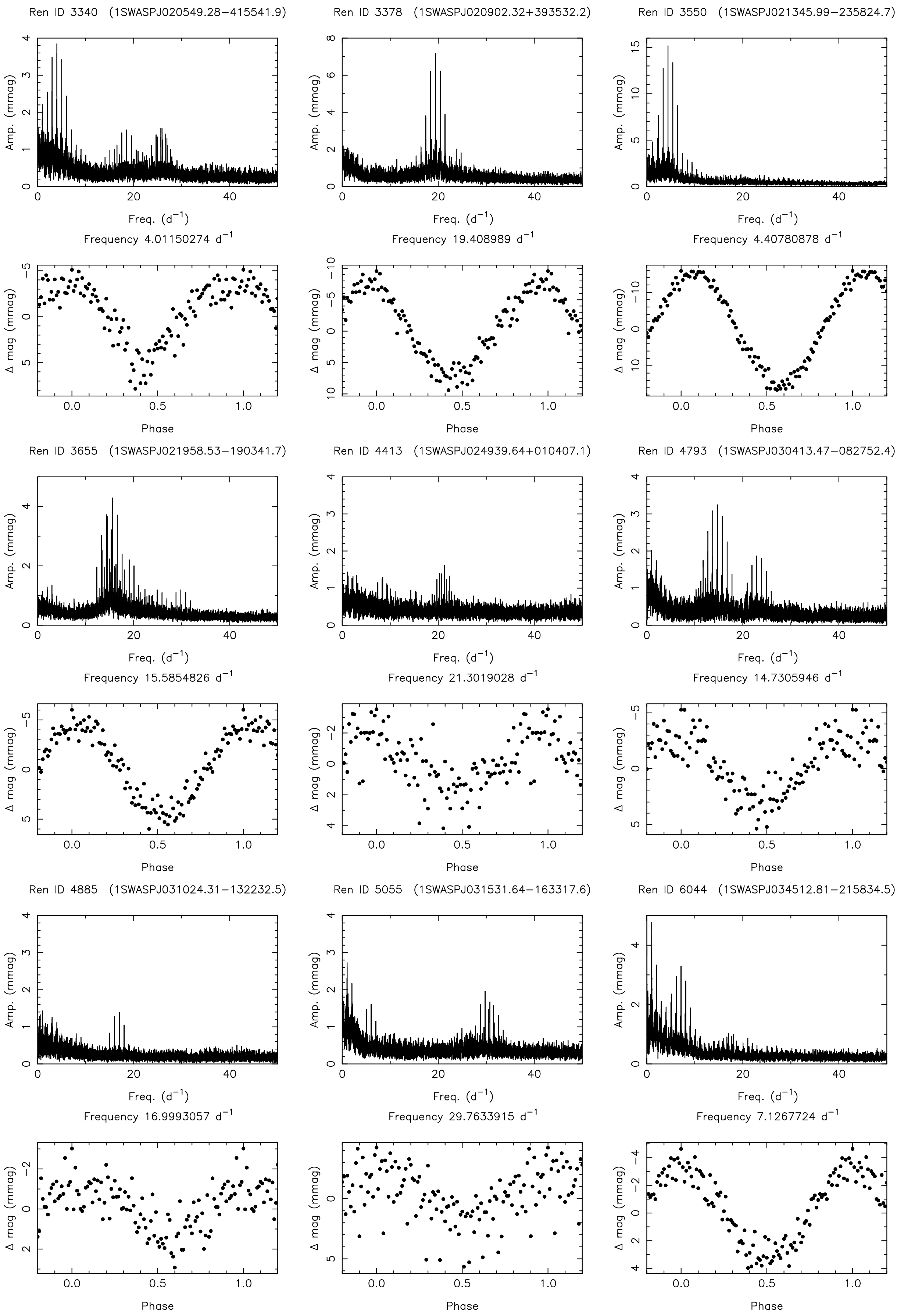

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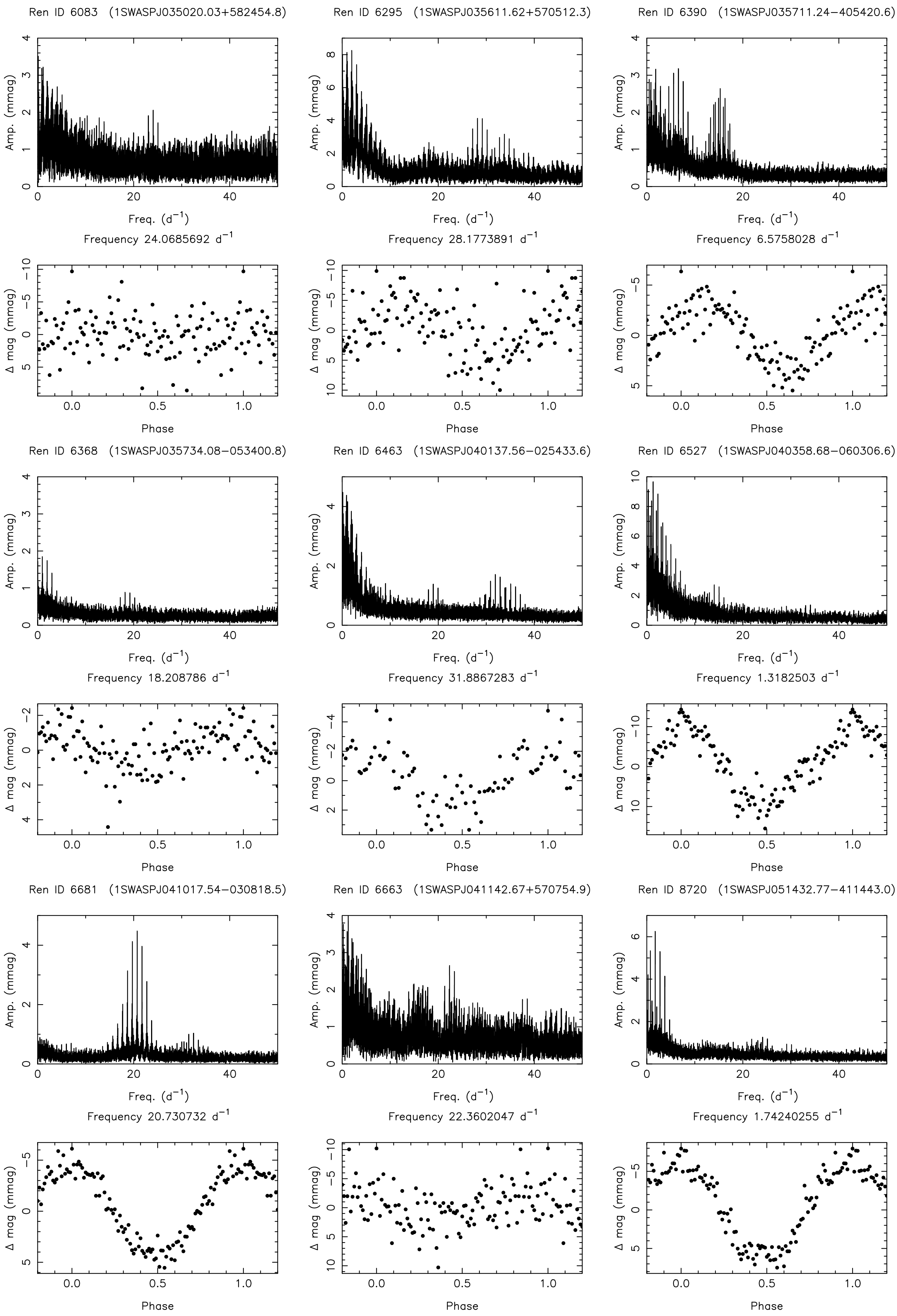

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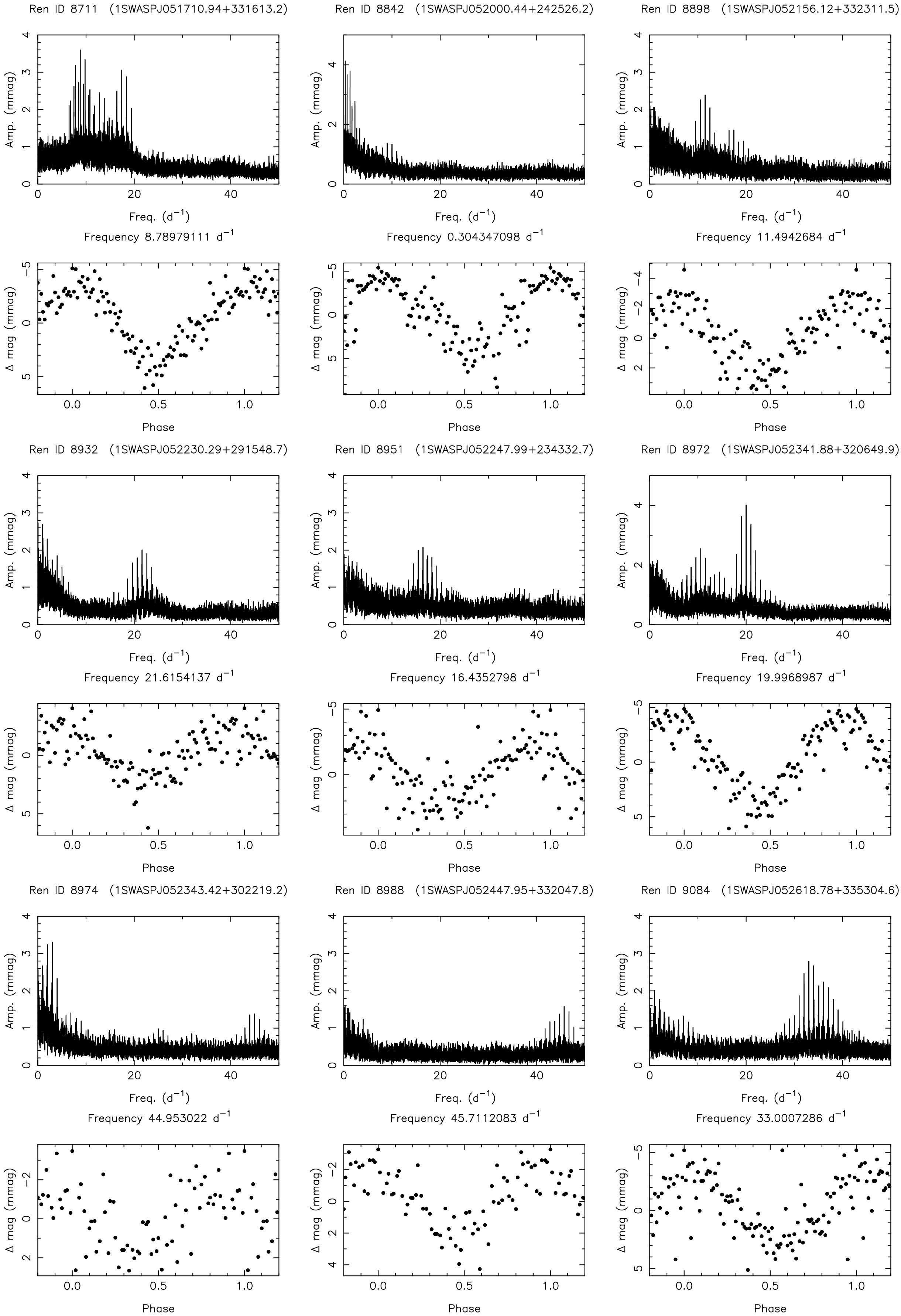

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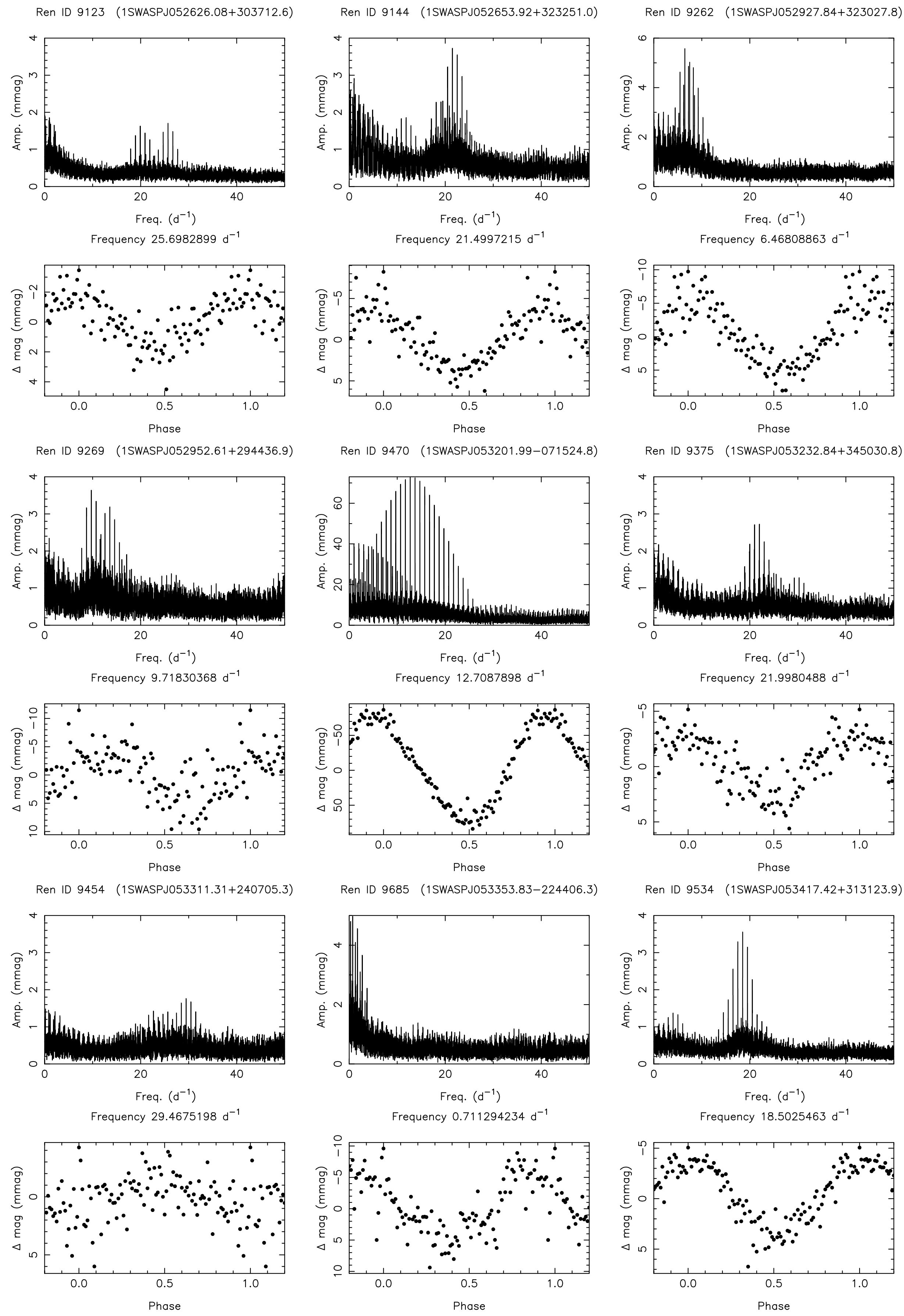

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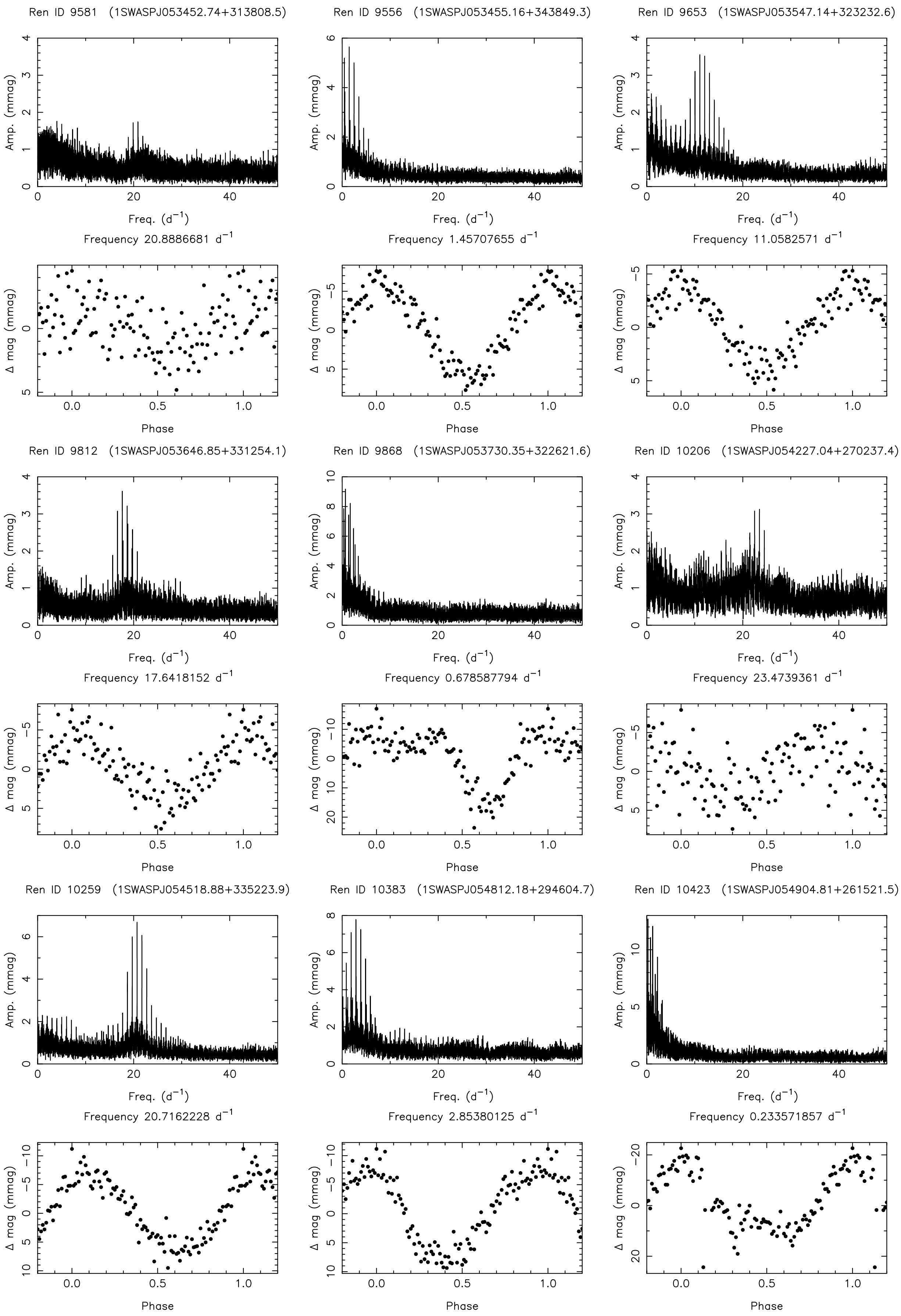

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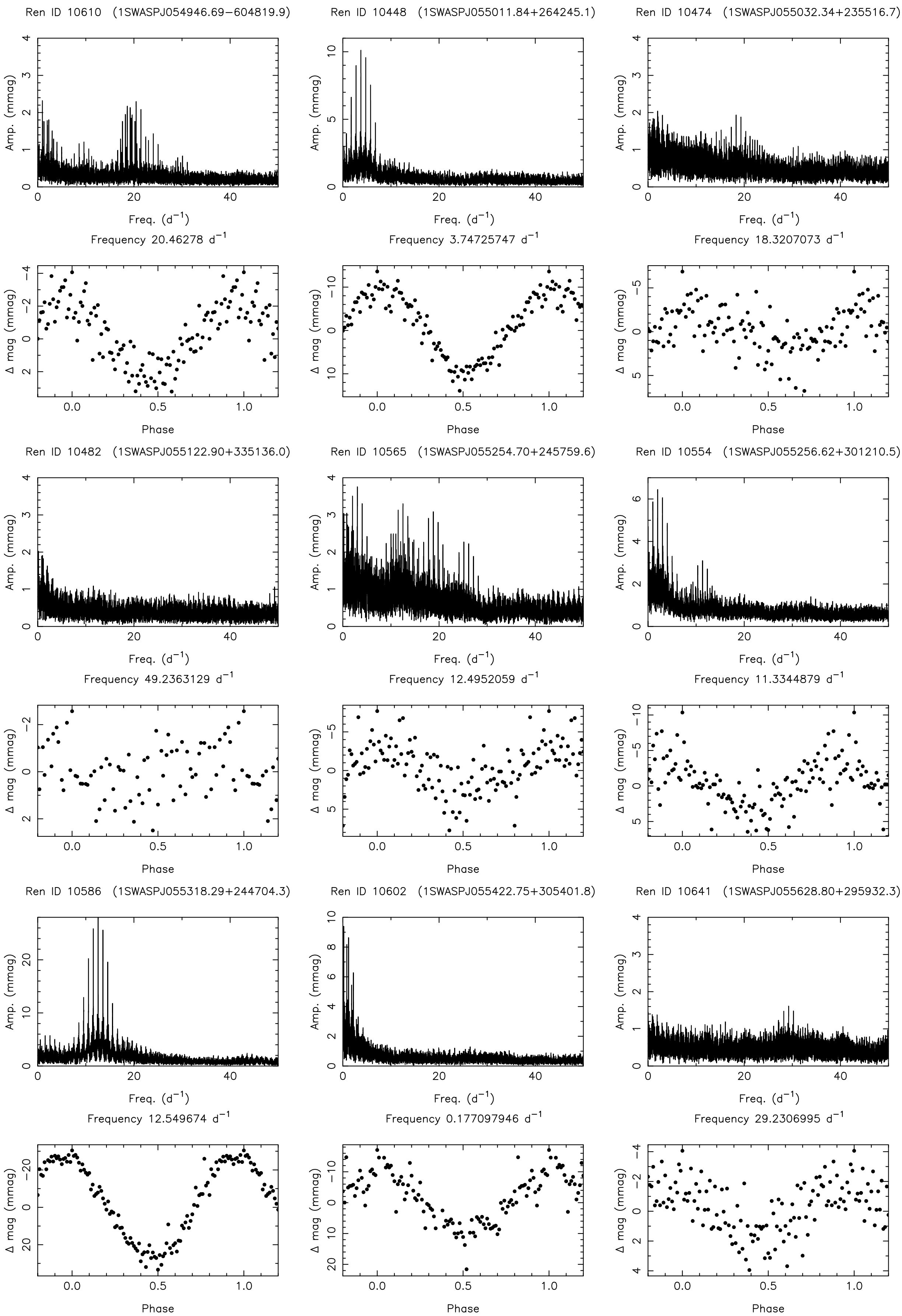

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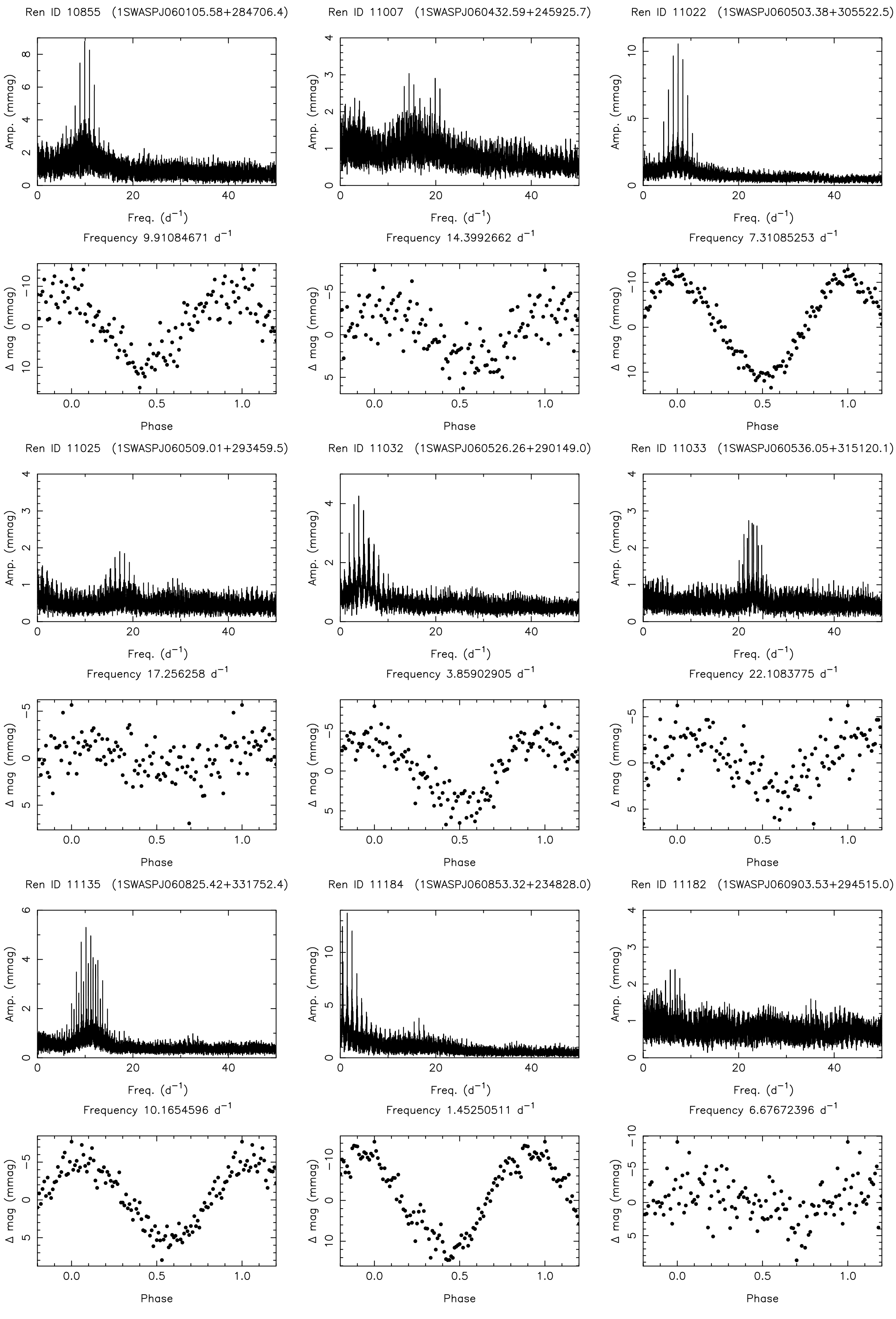

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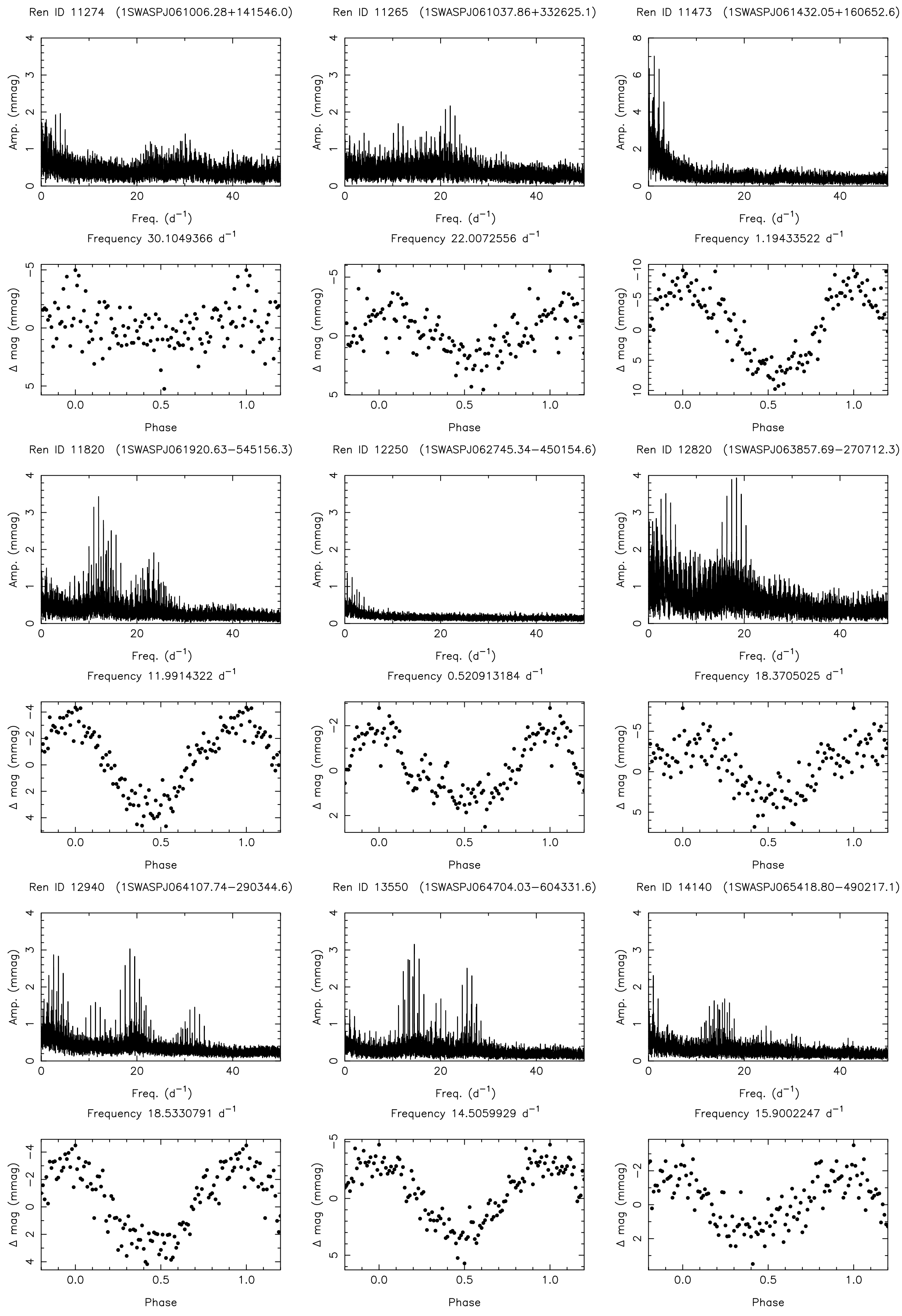

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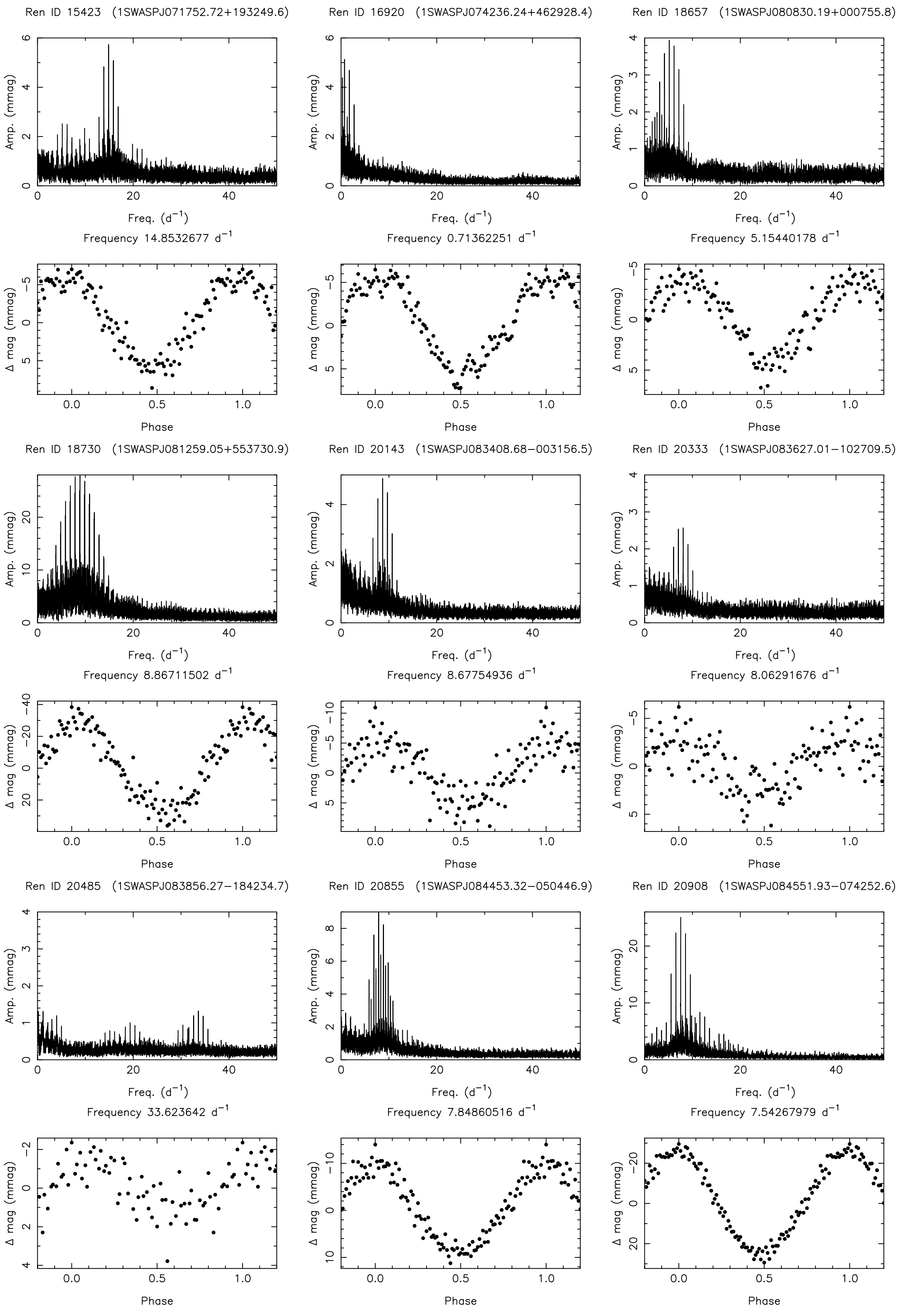

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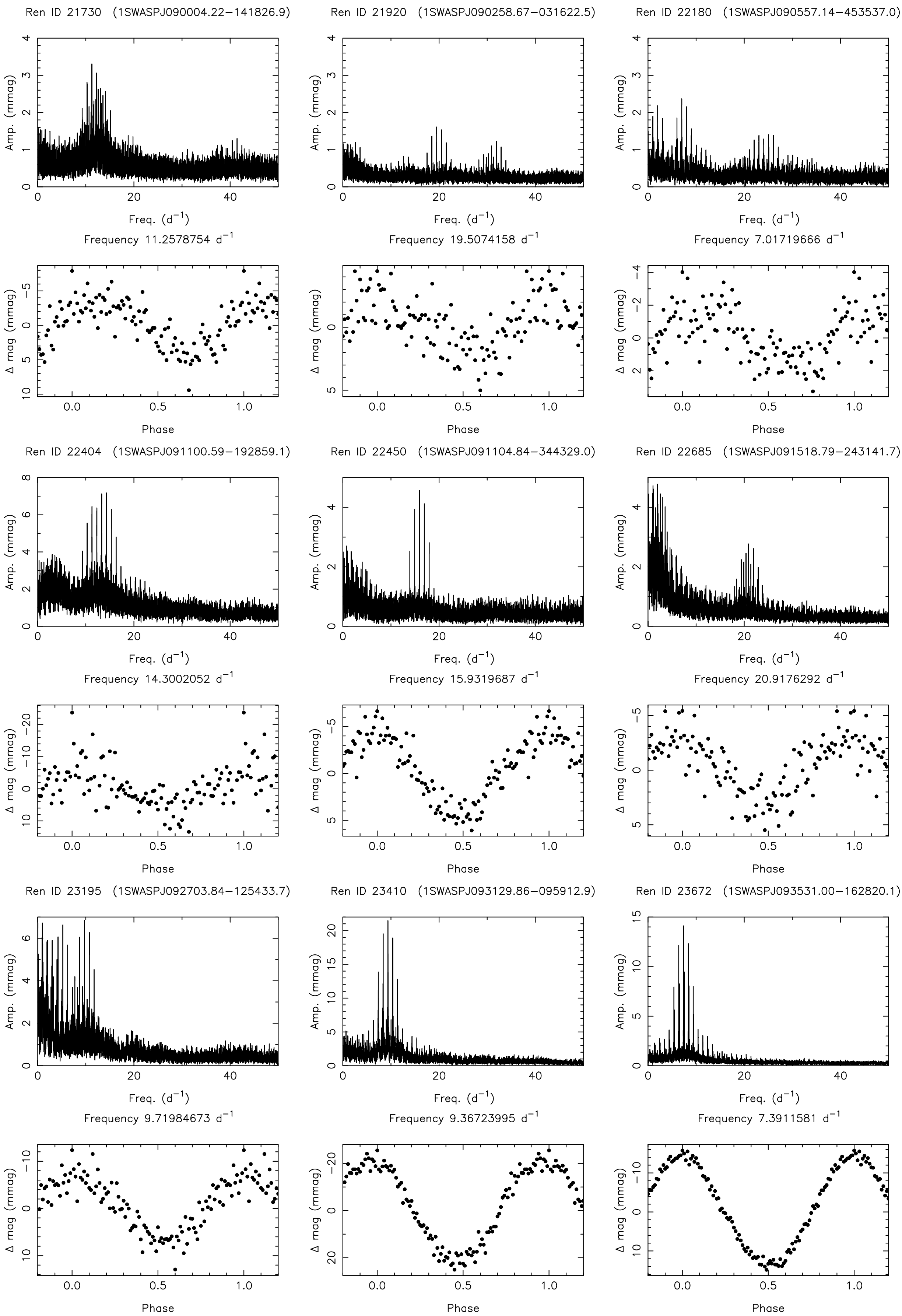

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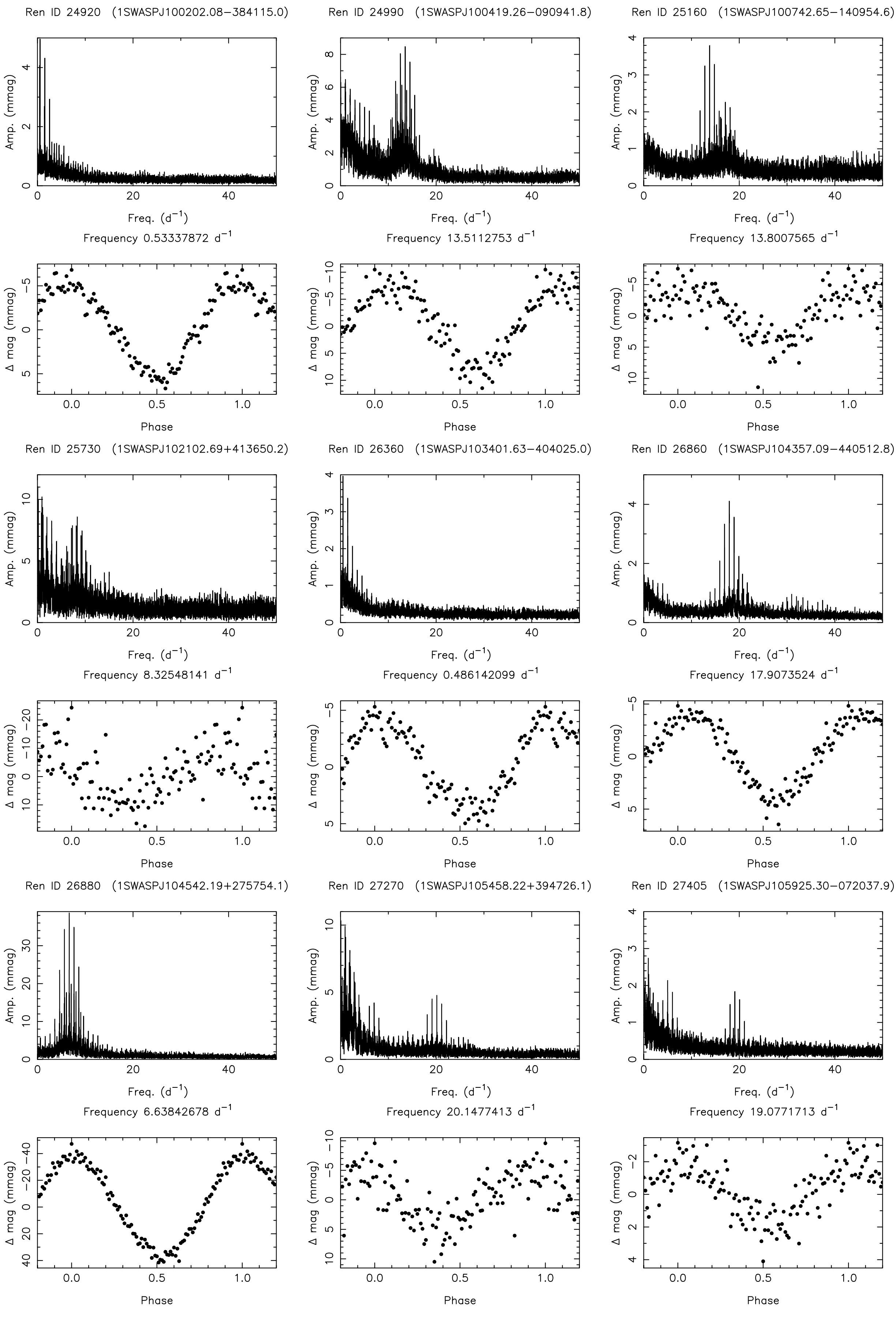

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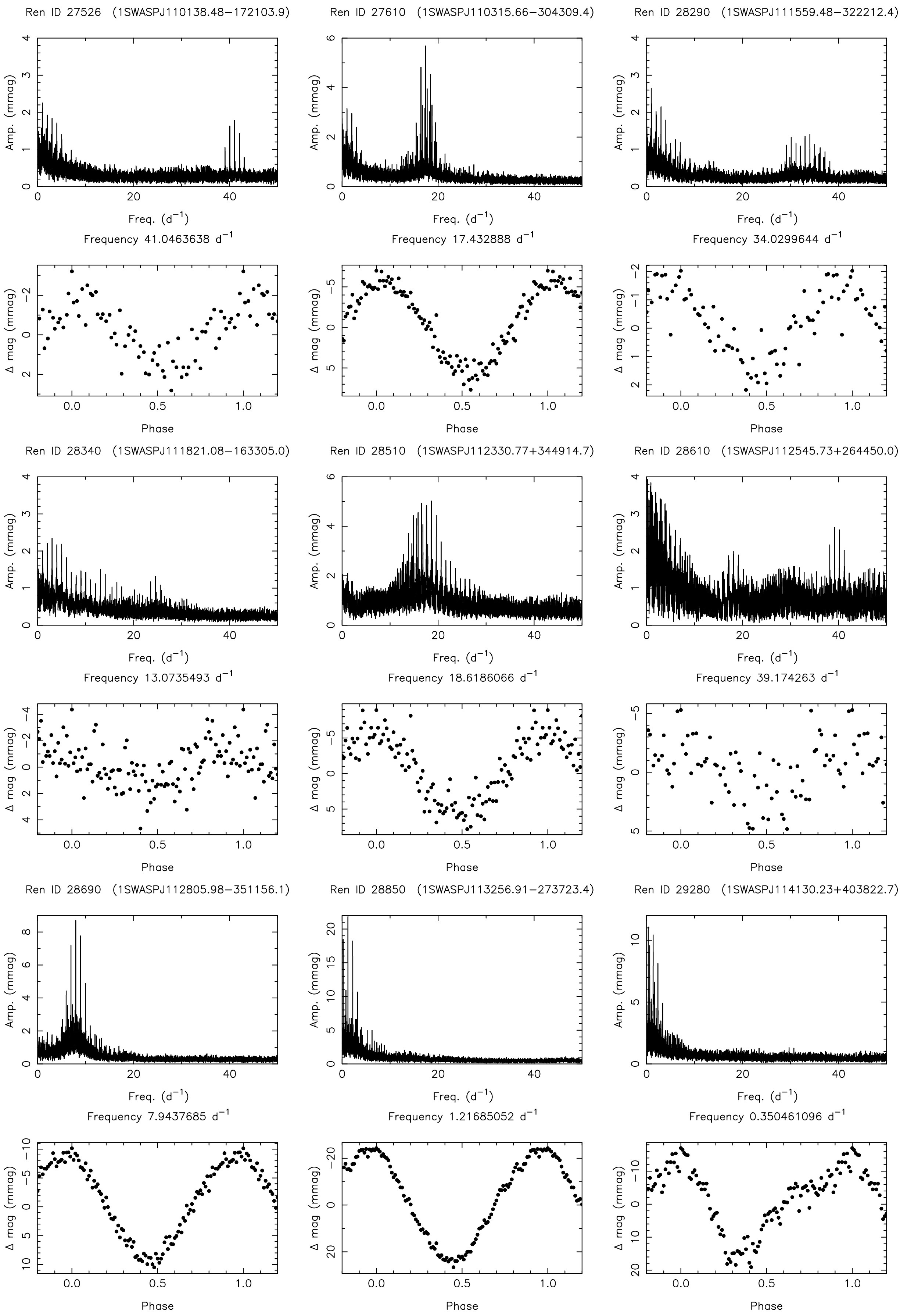

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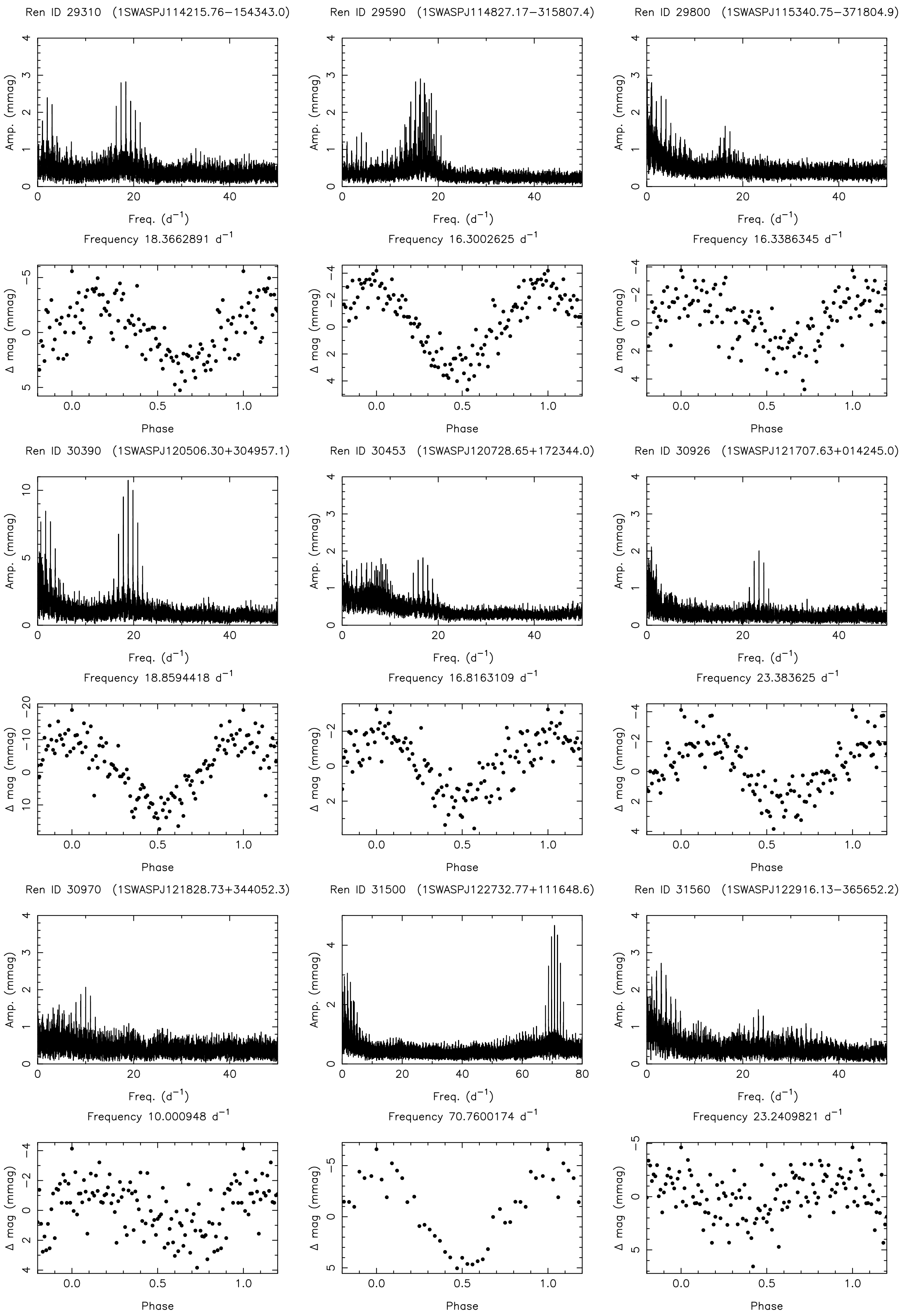

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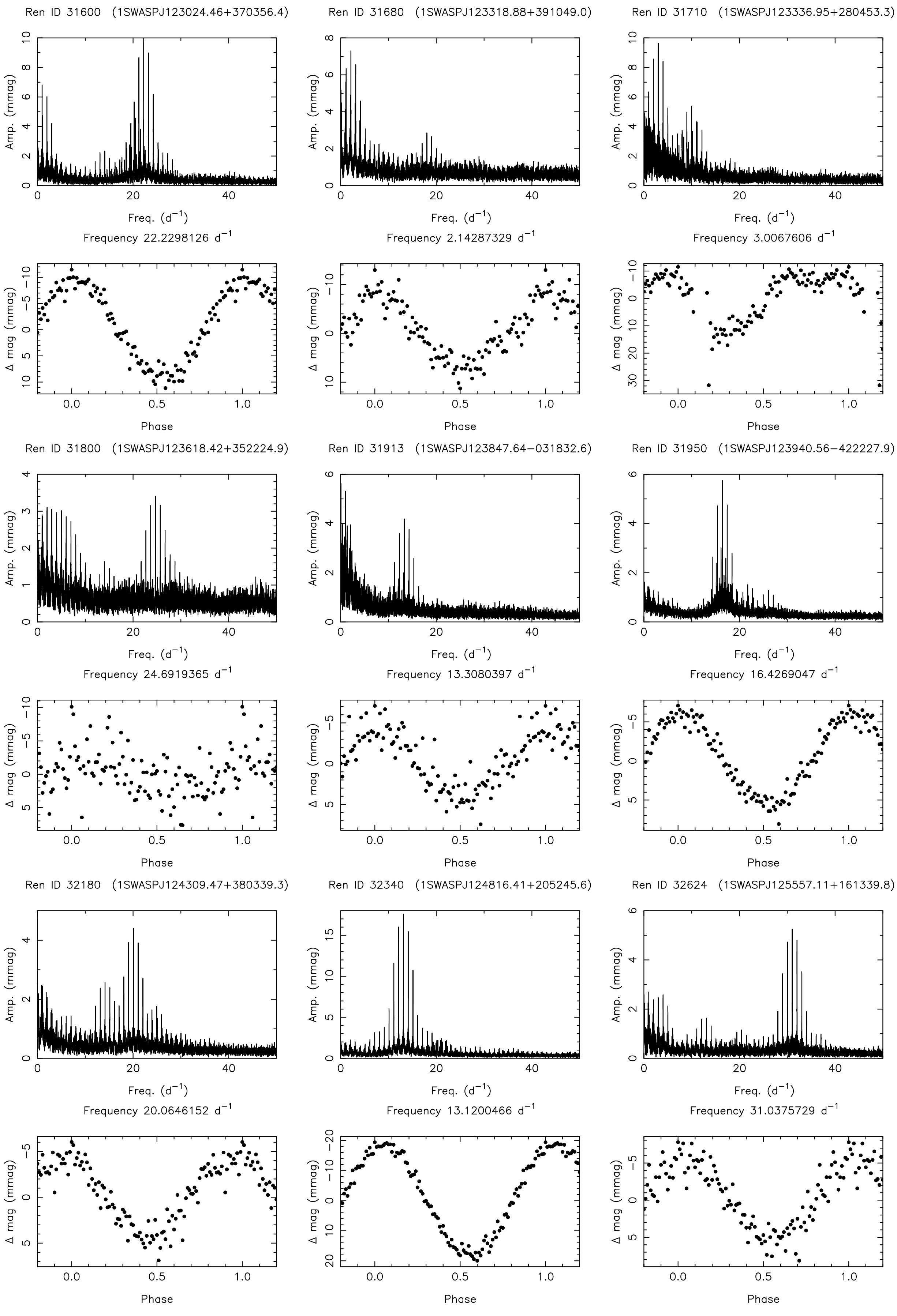

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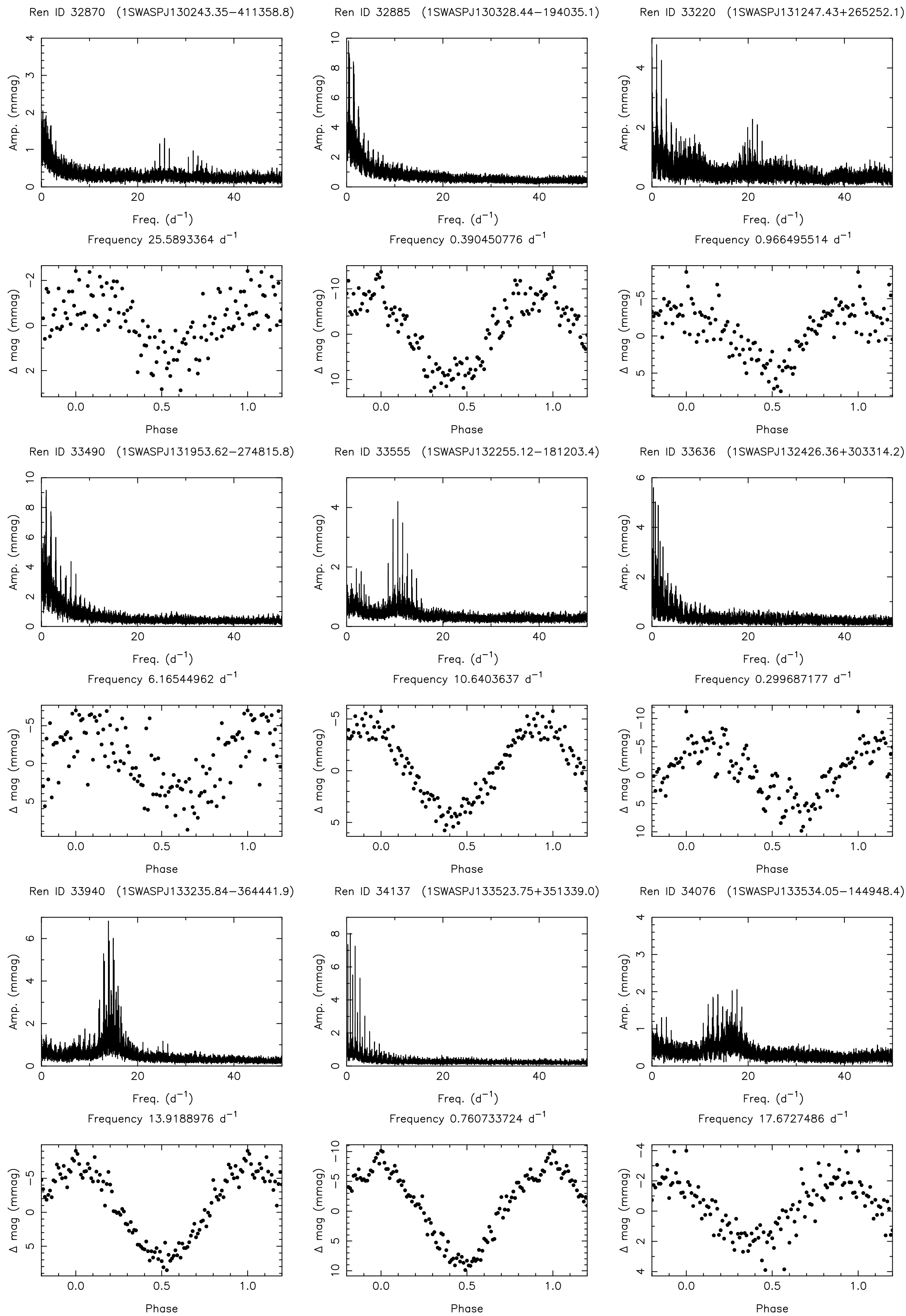

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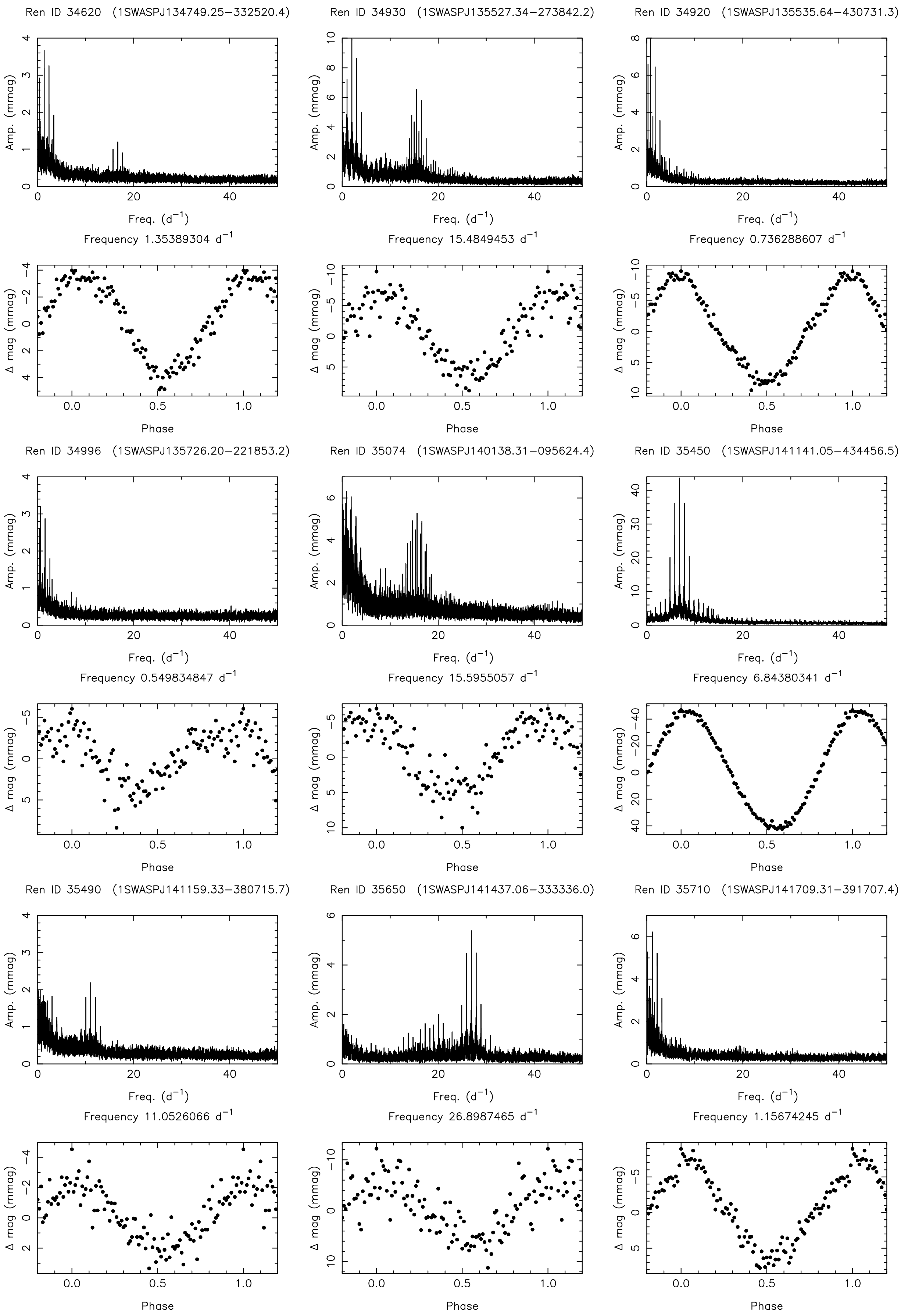

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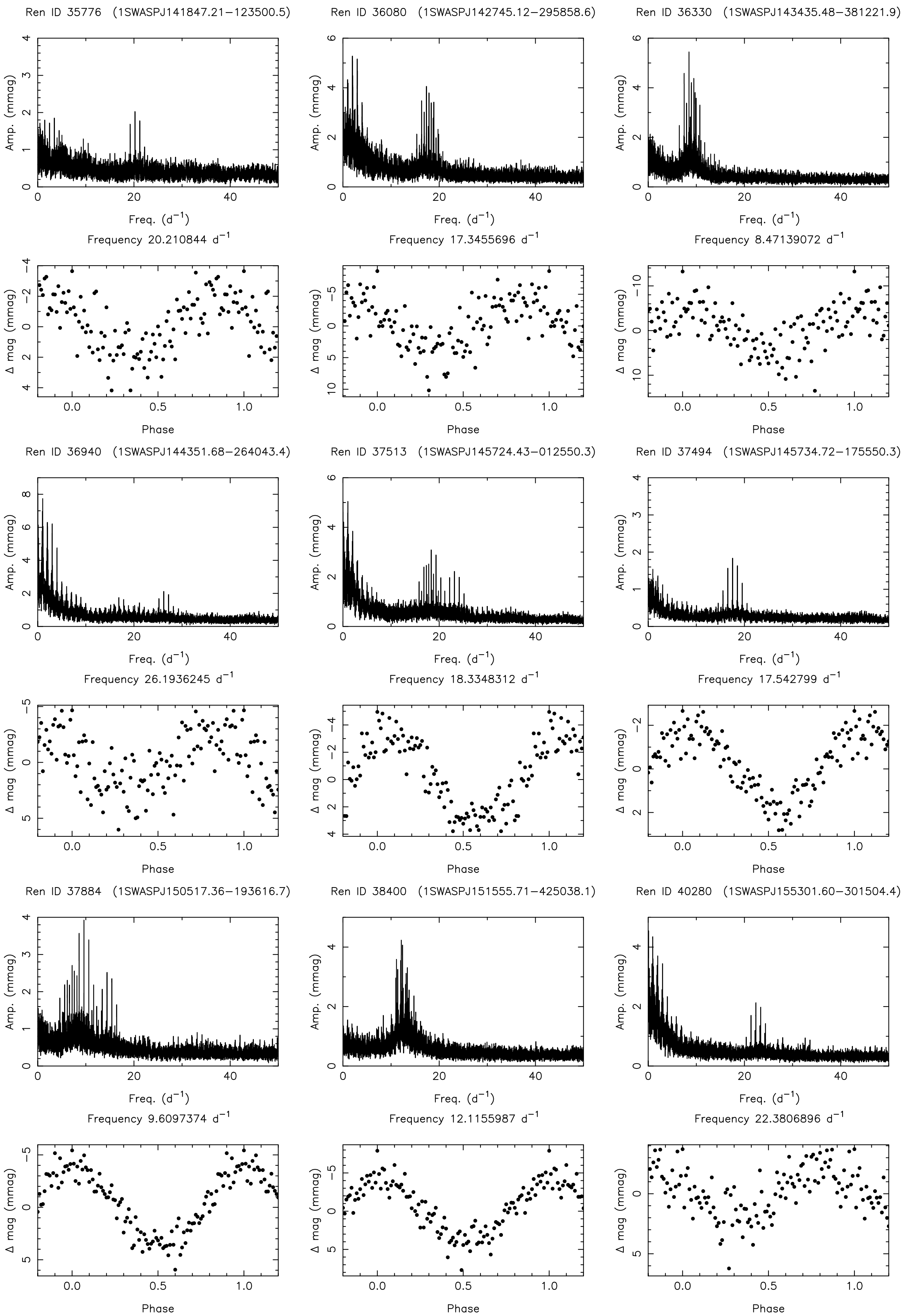

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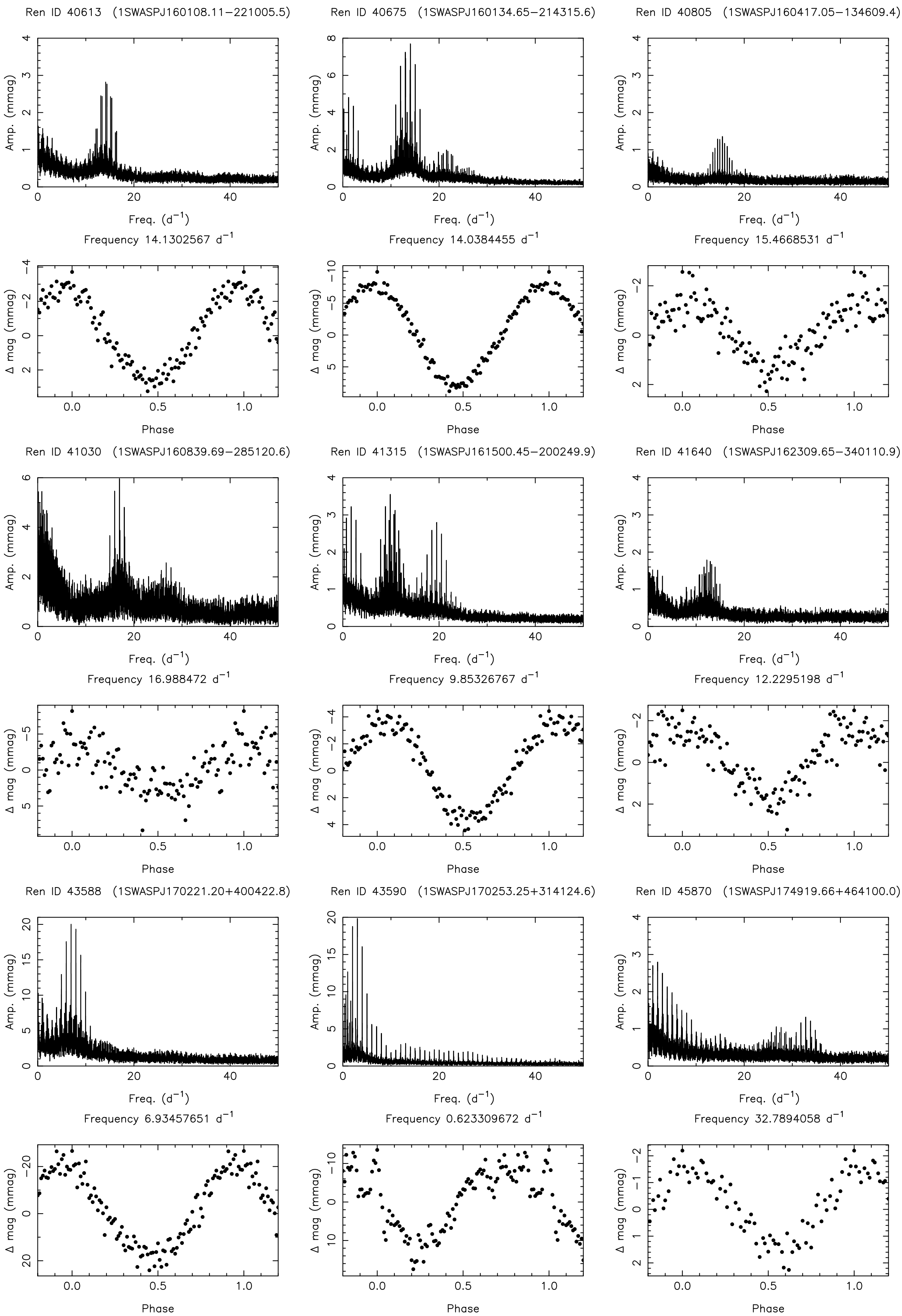

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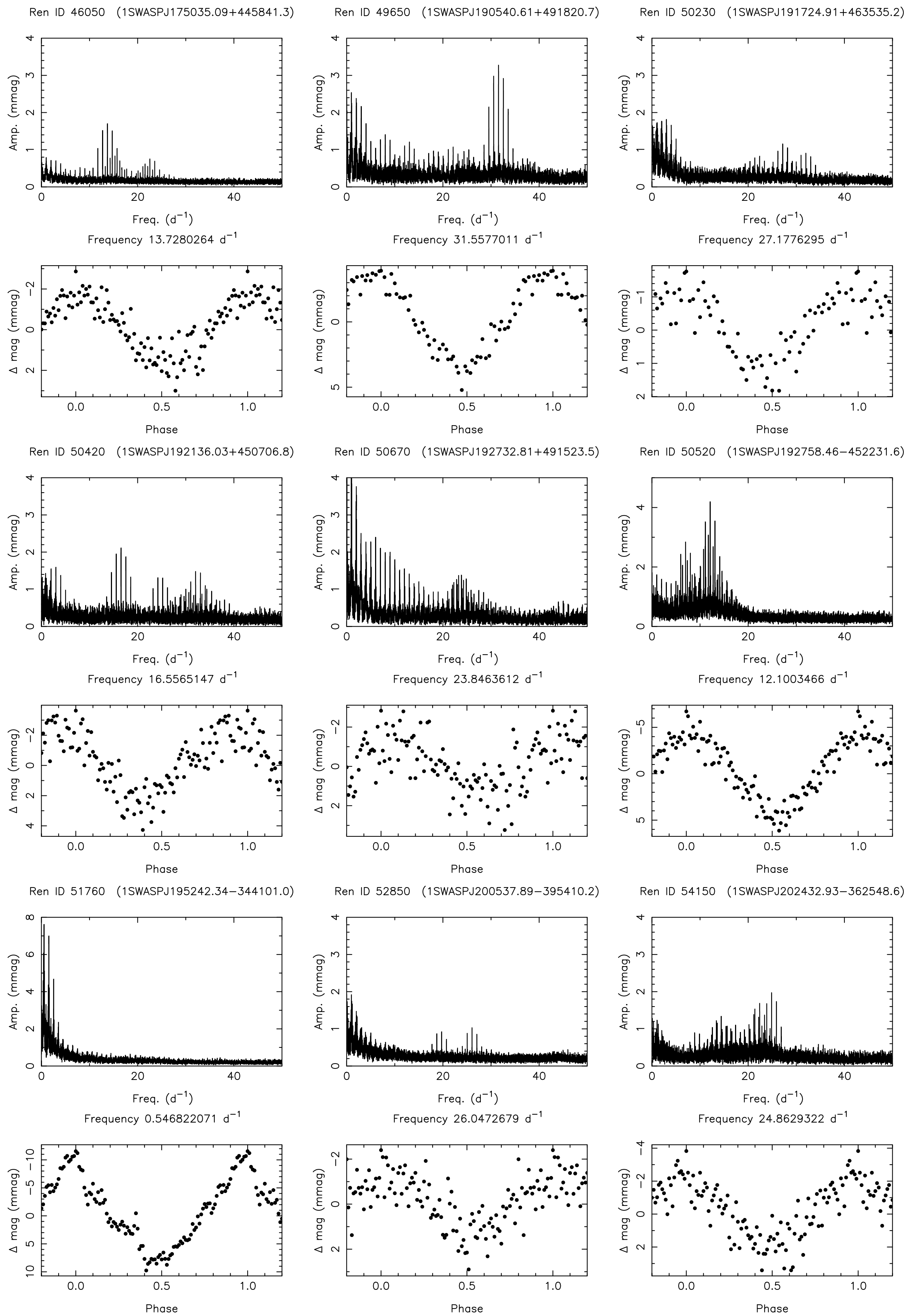

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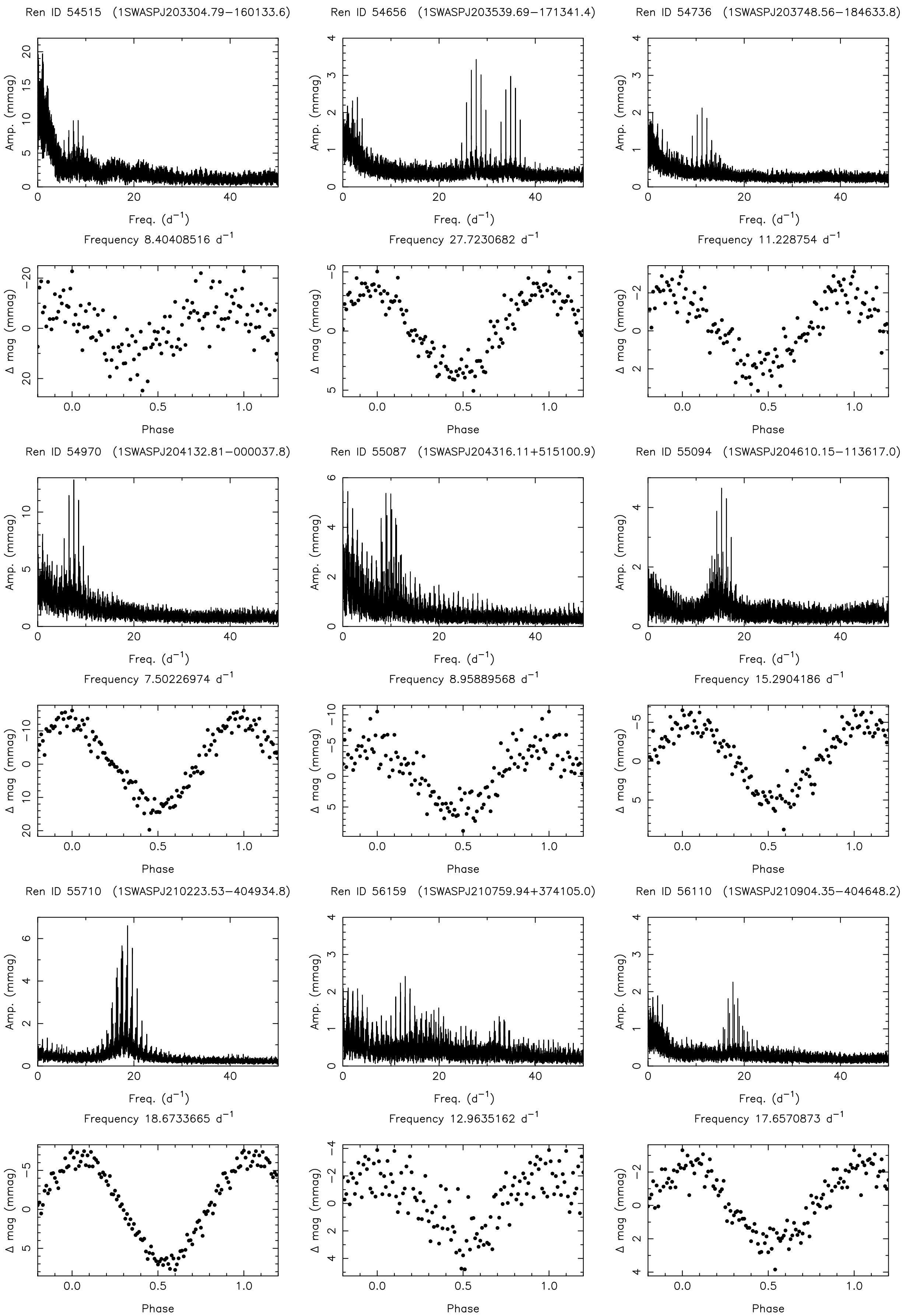

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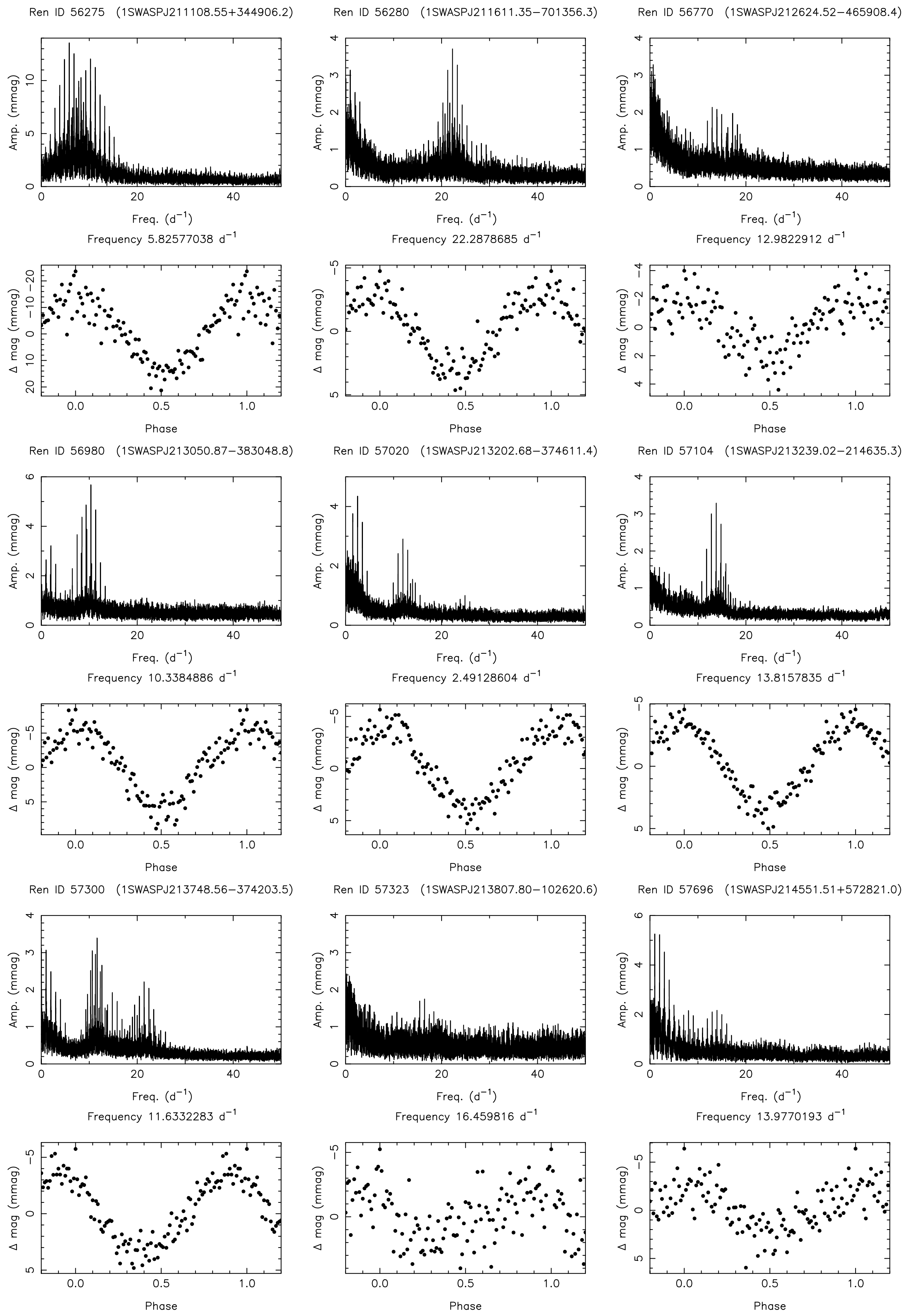

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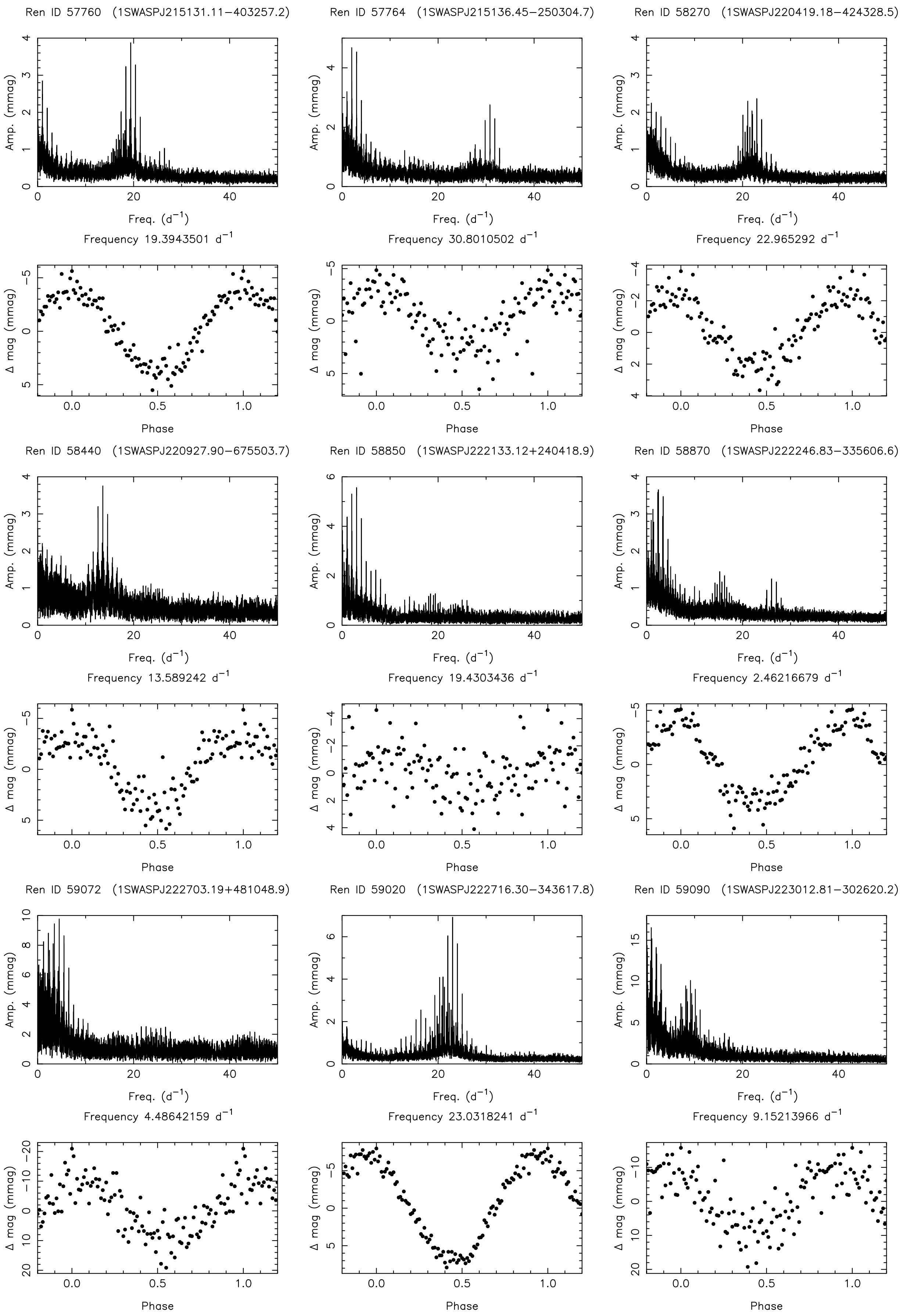

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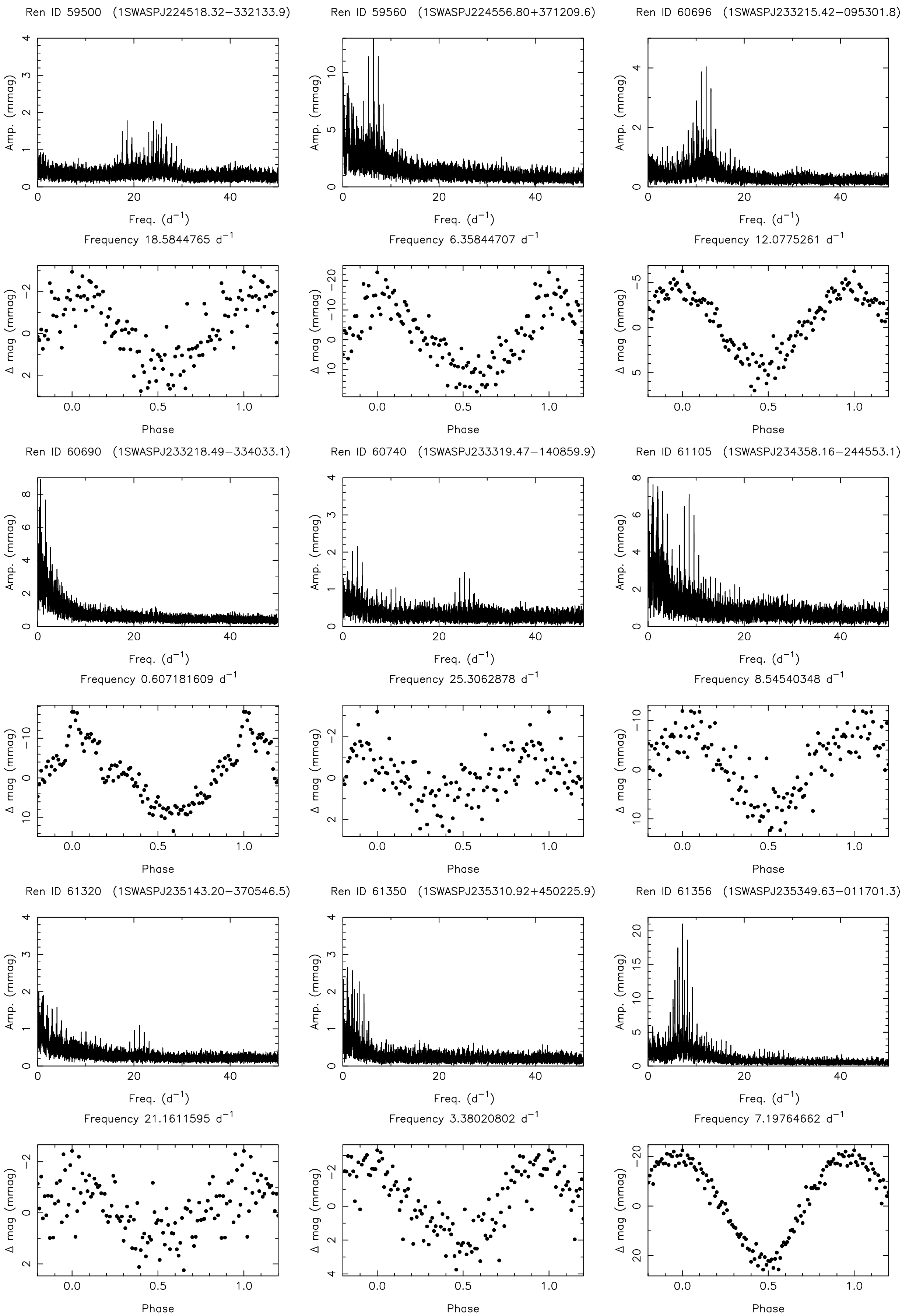

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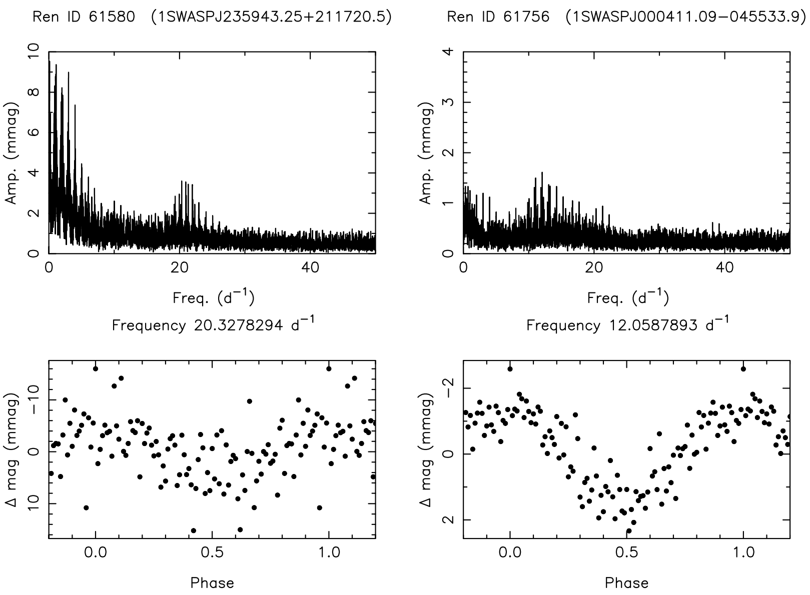

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